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RELIABILITY AND AVAILABILITY ANALYSIS FOR A MANUFACTURING NETWORK BY USING ACTIVE REDUNDANCY

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Abstract
The paper provides the reliability and availability analysis for a drill bit system. Using periodic inspection policy, if the unit is found to have suffered a failure, it can be repaired or replaced by an identical standby unit if available. The repair of individually failed units are done by single repair facility (one repair at a time) whereas the repair rate depends on the failure mode of the units.Keeping in mind the limitation of the Markov model the failure and repair rates are taken as constant. Active redundancy technique is used for enhancing the system availability where more than one machines are connected in parallel manner so that load on single machine can be reduced. The set of ordinary differential equations are obtained for the change of probability of being in respective system states with respect to time in each model. The system of rate equations is solved using Runge-Kutta method in MATLAB and thus derives availability, reliability and sensitivity analysis of this system. Sensitivity analysis is also carried out by varying the repair rate of the system. These results can be used for enhancing the system availability and reduced the down time and maintenance cost.

Keywords: Reliability, Availability, Markov Process, Series and Parallel system, State transition diagram

Introduction
Engineering systems have becoming complicating day by day, and rapidly increasing the cost of equipment challenges the plant personnel or job analyst that to maintain the system performance so that to produce the desirable profit under a predetermined time. However the failure is an inevitable phenomenon in an industrial system. With mechanical systems and particularly those containing heavy machinery, is difficult for the system analyst to maintain and predict its reliability. There can be considerable variance in the failure frequencies and average repair times of components which are not revealed by conventional methods of reliability analysis. Operational, environmental and maintenance conditions which may affect the validity of the generic reliability data used in assessing equipment and system availability also need to be studied. A subjective evaluation of the factors which can lead to uncertainties in the basic data is necessary to ensure that predictions based on the assumption of constant hazard rates are taken. Markov analysis is an important technique which is used for reliability and availability analysis of any plant layout. State transition diagram is used for showing the reliability behavior in which set of discrete states used to show the transition of the system from available to failure mode. Markov models consist of comprehensive representations of possible chains of events, i.e. transitions within systems which, in the case of reliability and availability analysis, correspond to sequences of failures and repair. The paper describes specific computational approach to reliability analysis of complex systems, which behavior is described by the Markov chain finite-state transition diagram which contains two no crossing sets of arbitrary configuration states, transitions between which is possible only through an one intermediate state. Reliability is defined as the probability that any component will operate successfully for a given period of time under specific operating and environmental conditions. For plant where the systems are repairable, the repair process as well as the failure process needs consideration. It is

usual (because of the relative limitations of the failure/repair data available) to consider steady state operation when the plant is assumed to have settled down and thus failure time and repair time are random variables. For this steady state model the availability, ***A,*** the probability to function on demand, is also a random variable and is defined as the ratio of the uptime to the total time. Hence

$$A = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}}$$

where
MTTF = Mean time to failure
MTTR = mean time to repair
With this simple expression it is possible to calculate global estimates of the availabilities of equipment and to combine these logically to determine the expected availability of a system.

Assumptions:
We consider this unit system with the following assumptions:

- All the states are independent and not depend upon the past history. Failure abd repair rates are constant throughout the process and follows exponential distribution.
- Repair or replacement facilities are available at sufficient extent.
- Only one failure is assumed at a time.
- Standby subsystems are used in the layout and it is used for the replacement of any failed subsystem.
- Failure and repair rates are statistically independent.
- Repair is conducted on the basis of priority of the sub-system.

System Description

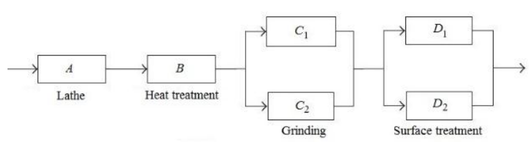


Figure 1*:* Layout of manufacturing cell

In this system one lathe, one heat treatment machine, 2 grinding machines and 2 surface treatment machines are connected in series manner whereas two grinders are in parallel manner and two surface treatment machines are also in parallel way. In active redundancy, all the machines are working and the load is evenly distributed among them.

Reliability of the system

This is a hybrid type of structure in which series and parallel both type of configuration are present. Reliability of the system can be evaluated by following formula. After analysis it had been seen that in lathe failure occur after 359.02 hours, in grinders failure occur after 562.136 hours, in HT failure occur after 1000 hours and in ST it occur after 185.53 hours.
λ = 1/ failure time(hrs)
Taking $\lambda1 = 0.00279$, $\lambda2 = 0.0001$, $\lambda3 = 0.00178$, $\lambda4 = 0.00178$, $\lambda5 = 0.00539$, $\lambda6 = 0.00539$,
$\mu1 = 0.033$, $\mu2 = 0.0271$, $\mu3 = 0.0461$, $\mu4 = 0.0461$, $\mu5 = 0.0167$ and $\mu6 = 0.0167$
In this layout Lathe, Heat treatment machine, Grinding and Surface treatment machines are in series. So reliability of the system is given by:

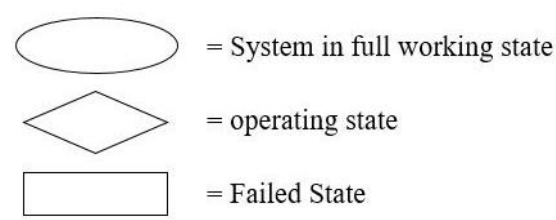
$$R1 = e^{-\lambda 1t}$$
$$R2 = e^{-\lambda 2t}$$
$$R3 = [1 - \{1 - e^{-\lambda 3t}\} * \{1 - e^{-\lambda 4t}\}]$$
$$R4 = [1 - \{1 - e^{-\lambda 5t}\} * \{1 - e^{-\lambda 6t}\}]$$

Rsys= R1*R2*R3*R4

Table 1: Manufacturing cell reliability estimation – Sensitivity analysis

Reliability at	Lathe	HT	Grind	ST	Rsys
8 hours	0.9779	0.9992	0.998	0.9982	0.9734
30 hours	0.9197	0.997	0.9973	0.9777	0.8941
60 hours	0.8458	0.994	0.9897	0.9236	0.7385
100 hours	0.75654	0.9901	0.9734	0.82638	0.6025
200hours	0.57235	0.9802	0.91028	0.56476	0.2884

Notation:



A=Lathe in working State
B= Heat treatment machine in working state
C= grinding machine 1 in working state
C_1= grinding machine 2 in working state
D= surface treatment machine 1 in working state
$D_{1=}$ surface treatment machine 2 in working state
a, b, c, d = lathe, heat treatment, grinding, surface treatment machines in failure state respectively
λ_i,i=1, 2, 3, 4, 5, 6 represents the failure rate of subsystem A, B, C, C_2, D, D_2

μ_i ,i=1, 2, 3, 4, 5, 6 represents the repair rate of subsystem A, B, C, C_2, D, D_2
O= Operating
F=Failure

Availability Analysis by Using Active Redundancy:
In active redundancy system load of the system is reduced by joining multiple components in parallel manner. Loads are distributed among there parallel components. Two Grinding machines and two surface treatment machines are connected to reduce the load of the system and improve availability of the system. Active redundancy transition diagram can be seen as under:

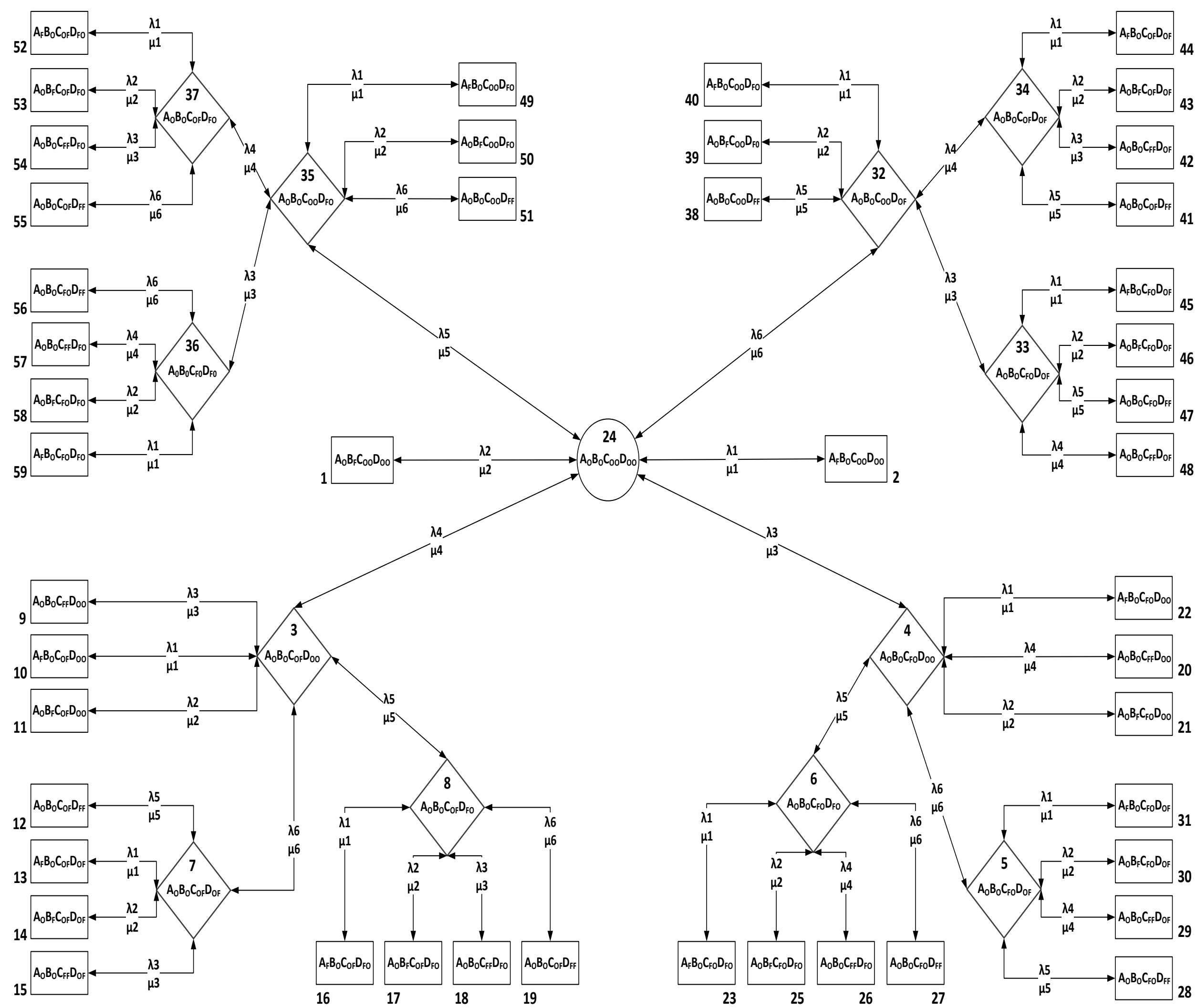


Fig 2: Transition Diagram in Active Redundancy

Table 1: Working and Failure State of the System

	A	B	C	C1	D	D1	System State Notation	System
1	O	F	O	O	O	O	1. $A_oB_fC_{oo}D_{oo}$	FAIL
2	F	O	O	O	O	O	2. $A_fB_oC_{oo}D_{oo}$	FAIL

3	O	O	O	F	O	O	3. $A_oB_oC_{of}D_{oo}$	WORKING
4	O	O	F	O	O	O	4. $A_oB_oC_{fo}D_{oo}$	WORKING
5	O	O	F	O	F	O	5. $A_oB_oC_{fo}D_{fo}$	WORKING
6	O	O	F	O	F	O	6. $A_oB_oC_{fo}D_{fo}$	WORKING
7	O	O	O	F	O	F	7. $A_oB_oC_{of}D_{of}$	WORKING
8	O	O	O	F	F	O	8. $A_oB_oC_{of}D_{fo}$	WORKING
9	O	O	F	F	O	O	9. $A_oB_oC_{ff}D_{oo}$	FAIL
10	F	O	O	F	O	O	10. $A_fB_oC_{of}D_{oo}$	FAIL
11	O	F	O	F	O	O	11. $A_oB_fC_{of}D_{oo}$	FAIL
12	O	O	O	F	F	F	12. $A_oB_oC_{of}D_{ff}$	FAIL
13	O	O	O	F	O	F	13.$A_fB_oC_{of}D_{of}$	FAIL
14	O	F	O	F	O	F	14. $A_oB_fC_{of}D_{of}$	FAIL
15	O	O	F	F	O	F	15. $A_oB_oC_{ff}D_{of}$	FAIL
16	F	O	O	F	F	O	16.$A_fB_oC_{of}D_{fo}$	FAIL
17	O	F	O	F	F	O	17.$A_oB_fC_{of}D_{fo}$	FAIL
18	O	O	F	F	F	O	18. $A_oB_oC_{ff}D_{fo}$	FAIL
19	O	O	O	F	F	F	19. $A_oB_oC_{of}D_{ff}$	FAIL
20	O	O	F	F	O	O	20. $A_oB_oC_{ff}D_{oo}$	FAIL

21	O	F	F	O	O	O	21. $A_oB_fC_{fo}D_{oo}$	FAIL
22	F	O	F	O	O	O	22. $A_fB_oC_{fo}D_{oo}$	FAIL
23	F	O	F	O	F	O	23. $A_fB_oC_{fo}D_{fo}$	FAIL
24	O	O	O	O	O	O	24.	WORKING
25	O	F	F	O	F	O	25. $A_oB_fC_{fo}D_{fo}$	FAIL
26	O	O	F	F	F	O	26. $A_oB_oC_{ff}D_{fo}$	FAIL
27	O	O	F	O	F	F	27. $A_oB_oC_{fo}D_{ff}$	FAIL
28	O	O	F	O	F	F	28. $A_oB_oC_{fo}D_{ff}$	FAIL
29	O	O	F	F	F	O	29. $A_oB_oC_{ff}D_{fo}$	FAIL
30	O	F	F	O	F	O	30. $A_oB_fC_{fo}D_{fo}$	FAIL
31	F	O	F	O	F	O	31. $A_fB_oC_{fo}D_{fo}$	FAIL
32	O	O	O	O	O	F	32. $A_oB_oC_{oo}D_{of}$	WORKING
33	O	O	F	O	O	F	33. $A_oB_oC_{fo}D_{of}$	WORKING
34	O	O	O	F	O	F	34. $A_oB_oC_{of}D_{of}$	WORKING
35	O	O	O	O	F	O	35. $A_oB_oC_{oo}D_{fo}$	WORKING
36	O	O	F	O	F	O	36. $A_oB_oC_{fo}D_{fo}$	WORKING
37	O	O	O	F	F	O	37. $A_oB_oC_{of}D_{fo}$	WORKING
38	O	O	O	O	F	F	38. $A_oB_oC_{oo}D_{ff}$	FAIL

39	O	F	O	O	O	F		39. $A_oB_fC_{oo}D_{of}$	FAIL
40	F	O	O	O	O	F		40. $A_fB_oC_{oo}D_{of}$	FAIL
41	O	O	O	F	F	F		41. $A_oB_oC_{of}D_{ff}$	FAIL
42	O	O	F	F	O	F		42. $A_oB_oC_{ff}D_{of}$	FAIL
43	O	O	O	F	O	F		43. $A_oB_fC_{of}D_{of}$	FAIL
44	F	O	O	F	O	F		44. $A_fB_oC_{of}D_{of}$	FAIL
45	F	O	F	O	O	F		45. $A_fB_oC_{fo}D_{of}$	FAIL
46	O	F	F	O	O	F		46. $A_oB_fC_{fo}D_{of}$	FAIL
47	O	O	F	O	F	F		47. $A_oB_oC_{fo}D_{ff}$	FAIL
48	O	O	F	F	O	F		48. $A_oB_oC_{ff}D_{of}$	FAIL
49	F	O	O	O	F	O		49. $A_fB_oC_{oo}D_{fo}$	FAIL
50	O	F	O	O	F	O		50. $A_oB_fC_{oo}D_{fo}$	FAIL
51	O	O	O	O	F	F		51. $A_oB_oC_{oo}D_{ff}$	FAIL
52	F	O	O	F	F	O		52. $A_fB_oC_{of}D_{fo}$	FAIL
53	O	F	O	F	F	O		53. $A_oB_fC_{of}D_{fo}$	FAIL
54	O	O	F	F	F	O		54.$A_oB_oC_{ff}D_{fo}$	FAIL
55	O	O	O	F	F	F		55. $A_oB_oC_{of}D_{ff}$	FAIL
56	O	O	F	O	F	F		56. $A_oB_oC_{fo}D_{ff}$	FAIL
57	O	O	F	F	F	O		57. $A_oB_oC_{ff}D_{fo}$	FAIL
58	O	F	F	O	F	O		58. $A_oB_fC_{fo}D_{fo}$	FAIL

59	F	O	F	O	F	O		59. $A_f B_o C_{fo} D_{fo}$	FAIL

SOLUTION OF SYSTEM MODEL

These are the mathematical differential equation showing transformation state of the system.

$$\frac{dP_1}{dt} = -\mu_2 P_1(t) + \lambda_2 P_{24}(t)$$

$$\frac{dP_2}{dt} = -\mu_1 P_2(t) + \lambda_1 P_{24}(t)$$

$$\frac{dP_3}{dt} = -(\mu_4 + \lambda_3 + \lambda_1 + \lambda_2 + \lambda_6 + \lambda_5)P_3(t) + \lambda_4 P_{24}(t) + \mu_3 P_9(t) + \mu_1 P_{10}(t) + \mu_2 P_{11}(t) + \mu_6 P_7(t) + \mu_5 P_8(t)$$

$$\frac{dP_4}{dt} = -(\mu_3 + \lambda_1 + \lambda_2 + \lambda_4 + \lambda_5 + \lambda_6)P_4(t) + \lambda_3 P_{24}(t) + \mu_4 P_{20}(t) + \mu_2 P_{21}(t) + \mu_1 P_{22}(t) + \mu_5 P_6(t) + \mu_6 P_5(t)$$

$$\frac{dP_5}{dt} = -(\mu_6 + \lambda_1 + \lambda_2 + \lambda_4 + \lambda_5)P_5(t) + \lambda_6 P_4(t) + \mu_1 P_{31}(t) + \mu_2 P_{30}(t) + \mu_4 P_{29}(t) + \mu_5 P_{28}(t)$$

$$\frac{dP_6}{dt} = -(\mu_5 + \lambda_1 + \lambda_2 + \lambda_4 + \lambda_6)P_6(t) + \lambda_5 P_4(t) + \mu_6 P_{27}(t) + \mu_4 P_{26}(t) + \mu_2 P_{25}(t) + \mu_1 P_{23}(t)$$

$$\frac{dP_7}{dt} = -(\mu_6 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_5)P_7(t) + \lambda_6 P_3(t) + \mu_5 P_{12}(t) + \mu_1 P_{13}(t) + \mu_2 P_{14}(t) + \mu_3 P_{15}(t)$$

$$\frac{dP_8}{dt} = -(\mu_5 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_6)P_8(t) + \lambda_5 P_3(t) + \mu_1 P_{16}(t) + \mu_2 P_{17}(t) + \mu_3 P_{18}(t) + \mu_6 P_{19}(t)$$

$$\frac{dP_9}{dt} = -\mu_3 P_9(t) + \lambda_3 P_3(t)$$

$$\frac{dP_{10}}{dt} = -\mu_1 P_{10}(t) + \lambda_1 P_3(t)$$

$$\frac{dP_{11}}{dt} = -\mu_2 P_{11}(t) + \lambda_2 P_3(t)$$

$$\frac{dP_{12}}{dt} = -\mu_5 P_{12}(t) + \boldsymbol{\lambda_5} P_7(t)$$

$$\frac{dP_{13}}{dt} = -\mu_1 P_{13}(t) + \lambda_1 P_7(t)$$

$$\frac{dP_{14}}{dt} = -\mu_2 P_{14}(t) + \boldsymbol{\lambda_2} P_7(t)$$

$$\frac{dP_{15}}{dt} = -\mu_3 P_{15}(t) + \lambda_3 P_7(t)$$

$$\frac{dP_{16}}{dt} = -\mu_1 P_{16}(t) + \lambda_1 P_8(t)$$

$$\frac{dP_{17}}{dt} = -\mu_2 P_{17}(t) + \lambda_2 P_8(t)$$

$$\frac{dP_{18}}{dt} = -\mu_3 P_{18}(t) + \lambda_3 P_8(t)$$

$$\frac{dP_{19}}{dt} = -\mu_6 P_{19}(t) + \lambda_6 P_8(t)$$

$$\frac{dP_{20}}{dt} = -\mu_4 P_{20}(t) + \lambda_4 P_4(t)$$

$$\frac{dP_{21}}{dt} = -\mu_2 P_{21}(t) + \lambda_2 P_4(t)$$

$$\frac{dP_{22}}{dt} = -\mu_1 P_{22}(t) + \lambda_1 P_4(t)$$

$$\frac{dP_{23}}{dt} = -\mu_1 P_{23}(t) + \lambda_1 P_6(t)$$

$$\frac{dP_{24}}{dt} = -(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)P_{24}(t) + \mu_2 P_1(t) + \mu_1 P_2(t) + \mu_4 P_3(t) + \mu_3 P_4(t) + \mu_5 P_{35}(t) + \mu_6 P_{32}(t)$$

$$\frac{dP_{25}}{dt} = -\mu_2 P_{25}(t) + \lambda_2 P_6(t)$$

$$\frac{dP_{26}}{dt} = -\mu_4 P_{26}(t) + \lambda_4 P_6(t)$$

$$\frac{dP_{27}}{dt} = -\mu_6 P_{27}(t) + \lambda_6 P_6(t)$$

$$\frac{dP_{28}}{dt} = -\mu_5 P_{28}(t) + \lambda_5 P_5(t)$$

$$\frac{dP_{29}}{dt} = -\mu_4 P_{29}(t) + \lambda_4 P_5(t)$$

$$\frac{dP_{30}}{dt} = -\mu_2 P_{30}(t) + \lambda_2 P_5(t)$$

$$\frac{dP_{31}}{dt} = -\mu_1 P_{31}(t) + \lambda_1 P_5(t)$$

$$\frac{dP_{32}}{dt} = -(\mu_6 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)P_{32}(t) + \lambda_6 P_{24}(t) + \mu_1 P_{40}(t) + \mu_2 P_{39}(t) + \mu_3 P_{33}(t) + \mu_4 P_{34}(t) + \mu_5 P_{38}(t)$$

$$\frac{dP_{33}}{dt} = -(\mu_3 + \lambda_1 + \lambda_2 + \lambda_4 + \lambda_5)P_{33}(t) + \lambda_3 P_{32}(t) + \mu_1 P_{45}(t) + \mu_2 P_{46}(t) + \mu_4 P_{48}(t) + \mu_5 P_{47}(t)$$

$$\frac{dP_{34}}{dt} = -(\mu_4 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_5)P_{34}(t) + \lambda_4 P_{32}(t) + \mu_1 P_{44}(t) + \mu_2 P_{43}(t) + \mu_3 P_{42}(t) + \mu_5 P_{41}(t)$$

$$\frac{dP_{35}}{dt} = -(\mu_5 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_6)P_{35}(t) + \lambda_5 P_{24}(t) + \mu_1 P_{49}(t) + \mu_3 P_{36}(t) + \mu_2 P_{50}(t) + \mu_6 P_{51}(t) + \mu_4 P_{37}(t)$$

$$\frac{dP_{36}}{dt} = -(\mu_3 + \lambda_1 + \lambda_2 + \lambda_4 + \lambda_6)P_{36}(t) + \lambda_3 P_{35}(t) + \mu_1 P_{59}(t) + \mu_2 P_{58}(t) + \mu_4 P_{57}(t) + \mu_6 P_{56}(t)$$

$$\frac{dP_{37}}{dt} = -(\mu_4 + \lambda_1 + \lambda_2 + \lambda_3 + \lambda_6)P_{37}(t) + \lambda_4 P_{35}(t) + \mu_1 P_{52}(t) + \mu_2 P_{53}(t) + \mu_4 P_{54}(t) + \mu_6 P_{55}(t)$$

$$\frac{dP_{38}}{dt} = -\mu_5 P_{38}(t) + \lambda_5 P_{32}(t)$$
$$\frac{dP_{39}}{dt} = -\mu_2 P_{39}(t) + \lambda_2 P_{32}(t)$$
$$\frac{dP_{40}}{dt} = -\mu_1 P_{40}(t) + \lambda_1 P_{32}(t)$$
$$\frac{dP_{41}}{dt} = -\mu_5 P_{41}(t) + \lambda_5 P_{34}(t)$$
$$\frac{dP_{42}}{dt} = -\mu_3 P_{42}(t) + \lambda_3 P_{34}(t)$$
$$\frac{dP_{43}}{dt} = -\mu_2 P_{43}(t) + \lambda_2 P_{34}(t)$$
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$$\frac{dP_{45}}{dt} = -\mu_1 P_{45}(t) + \lambda_1 P_{33}(t)$$
$$\frac{dP_{46}}{dt} = -\mu_2 P_{46}(t) + \lambda_2 P_{33}(t)$$
$$\frac{dP_{47}}{dt} = -\mu_5 P_{47}(t) + \lambda_5 P_{33}(t)$$
$$\frac{dP_{48}}{dt} = -\mu_4 P_{48}(t) + \lambda_4 P_{33}(t)$$
$$\frac{dP_{49}}{dt} = -\mu_1 P_{49}(t) + \lambda_1 P_{35}(t)$$
$$\frac{dP_{50}}{dt} = -\mu_2 P_{50}(t) + \lambda_2 P_{35}(t)$$
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$$\frac{dP_{53}}{dt} = -\mu_2 P_{53}(t) + \lambda_2 P_{37}(t)$$
$$\frac{dP_{54}}{dt} = -\mu_3 P_{54}(t) + \lambda_3 P_{37}(t)$$
$$\frac{dP_{55}}{dt} = -\mu_6 P_{55}(t) + \lambda_6 P_{37}(t)$$
$$\frac{dP_{56}}{dt} = -\mu_6 P_{56}(t) + \lambda_6 P_{36}(t)$$
$$\frac{dP_{57}}{dt} = -\mu_4 P_{57}(t) + \lambda_4 P_{36}(t)$$
$$\frac{dP_{58}}{dt} = -\mu_2 P_{58}(t) + \lambda_2 P_{36}(t)$$
$$\frac{dP_{59}}{dt} = -\mu_1 P_{59}(t) + \lambda_1 P_{36}(t)$$

RELIABILITY ANALYSIS OF MANUFACTURING CELL

This is a hybrid type of structure in which series and parallel both type of configuration are present. Reliability of the system can be evaluated by following formula. After analysis it had been seen that in lathe failure occur after 359.02 hours, in grinders failure occur after 562.136 hours(after 60000 components), in HT failure occur after 1000 hours(after 80000 components), in ST it occur after 185.53 hours.

λ = 1/ failure time(hrs)

Taking λ1 = 0.00279, λ2 = 0.0001, λ3 = 0.00178, λ4 = 0.00178, λ5 = 0.00539, λ6 = 0.00539,
μ1 = 0.033, μ2 = 0.0271, μ3 = 0.0461, μ4 = 0.0461, μ5 = 0.0167 and μ6 = 0.0167

In this layout Lathe, Heat treatment machine, Grinding and Surface treatment machines are in series. So reliability of the system is given by:

$R1 = e^{-\lambda 1t}$

$R2 = e^{-\lambda 2t}$

$R3 = [1 - \{1 - e^{-\lambda 3t}\} * \{1 - e^{-\lambda 4t}\}]$

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Rsys= R1*R2*R3*R4

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100 hours	0.75654	0.9901	0.9734	0.82638	0.6025
200hours	0.57235	0.9802	0.91028	0.56476	0.2884

Availability of the System

Availability can be evaluated with the help of available state in which system is working by using failure and repair rate of each component.

Availability= $P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_{24} + P_{32} + P_{33} + P_{34} + P_{45} + P_{36} + P_{37}$

Av = 82.69**%**

Table 3: Manufacturing cell availability estimation

Time in hours	Availability
30	0.9305
60	0.8884
90	0.8629
120	0.8469
140	0.8396
160	0.8341
180	0.8300
210	0.8256
240	0.8227
270	0.8208
300	0.8195
330	0.8187
360	0.8181

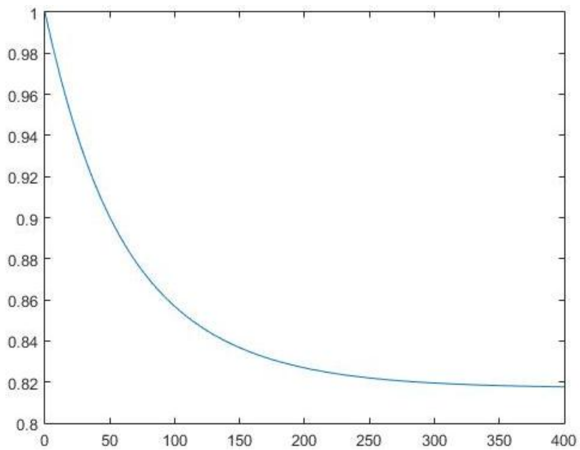

Figure 3. Graph Between Availability and Time(hours)

Sensitivity Analysis

Sensitivity refers to the change in the result obtained when one or more independent parameters considered in the calculations are varied. Sensitivity Analysis is a technique to check the sensitivity of the solution obtained. For that, fixing time, t=200 hours and keeping other factors constant, only one of the parameters is varied at a time.

Taking $\lambda 1 = 0.00279$, $\lambda 2 = 0.0001$, $\lambda 3 = 0.00178$, $\lambda 4 = 0.00178$, $\lambda 5 = 0.00539$, $\lambda 6 = 0.00539$, $\mu 1 = 0.033$, $\mu 2 = 0.0271$, $\mu 3 = 0.0461$, $\mu 4 = 0.0461$, $\mu 5 = 0.0167$, $\mu 6 = 0.0167$ all these data constant and changing the value of μ_1 :

Table 4: Variation of availability with change of repair rate of lathe

μ_1	0.033	0.066	0.132	0.246
Availability	0.8269	0.8568	0.8725	0.8799

Table 5: Variation of availability with change of repair rate of heat treatment plant

μ_2	0.0271	0.054	0.108	0.216
Availability	0.8269	0.8281	0.8288	0.8291

Table 6: Variation of availability with change of repair rate of grinding machine 1

μ_3	0.0461	0.092	0.184	0.368
Availability	0.8269	0.8281	0.8287	0.8291

Table 7: Variation of availability with change of repair rate of grinding machine 2

μ_4	0.0461	0.092	0.184	0.368
Availability	0.8269	0.8291	0.8304	0.8311

Table 8: Variation of availability with change of repair rate of surface treatment machine 1

μ_5	0.0167	0.033	0.066	0.132
Availability	0.8269	0.8604	0.8850	0.8997

Table 9: Variation of availability with change of repair rate of surface treatment machine 2

μ_6	0.0167	0.033	0.066	0.132
Availability	0.8269	0.8604	0.8850	0.8997

CONCLUSION

The method of calculation of stationary probabilities of states of the original system includes it decomposition into separate subsystems and calculation of stationary probabilities of the original model from the known values of stationary probabilities of subsystems using the proposed transitional equations. After completing all the analysis it is observed that availability of the system was 82.69% and it is found that that availability increasing continuously on increasing repair rates and surface treatment of the machines.

While the reliability of the system decreases as time duration increases. The availability of mechanical equipment can have a significant impact on plant profitability. Thus availability assessment of new installations should be an essential part of the design process. The proposed analysis is useful for the plant engineers to optimize their maintenance resources and also helpful for them in taking decisions for appropriate maintenance policy.

REFERENCES

[1] Atul Goyal and Parvinder Singh (2000), “Behavior Analysis of a Biscuit Making Plant using Markov Regenerative Modeling”, ISSN : 2319 – 3182, Volume-2, Issue-3.
[2] Atul Goyal, S.K. Sharma, Pardeep Gupta (2001), “Availability analysis of a part of rubber tube production system under preemptive resume priority repair”, International Journal of Industrial Engineering, 16(4), 260-269.
[3] C.D. Rakopoulos and E.G. Giakoumis (2008) Availability analysis of a turbocharged diesel engine operating under transient load conditions”, Energy 291085–1104
[4] C.D. Rakopoulos, M.A. Scott, D.C. Kyritsis, E.G. Giakoumis(2006), “Availability analysis of hydrogen/natural gas blends combustion in internal combustion engines”, Energy 33 248–255.

[5] Cher (2006), "Optimal, opportunistic maintenance policy using genetic algorithms". Journal of Quality in Maintenance Engineering, Volume 1, No. 3, 25-34.
[6] Dhillon B.S. (1987),"Engineering Maintenance: A Modern Approach",CRC Press, Boca Raton, Florida.
[7] Dhillon B.S. (1992), "Reliability and Availability analysis of a system with warm standby and common cause failures", Micro electron Reliability, Volume 33, No. 9, pp. 1343-1349.
[8] Distefano and Puliafito (2009), "Dependability evaluation with dynamic reliability block diagrams and dynamic fault trees", Dependable and Secure Computing, IEEE Transactions on Volume:6, Issue:1, ISSN :1545-5971, Page(s):4 – 17.
[9] Enrico Zio and Francesco Di Maio (2009], "Processing dynamic scenarios from a reliability analysis of a nuclear power plant digital instrumentation and control system", Energy Department, Polytechnic of Milan Via Ponzio 34/3, 20133 Milano, Italy, Annals of Nuclear Energy, Volume 36, Issue 9, Pages 1386–1399.
[10] F.J.G. Carazas, C.H. Salazar, G.F.M. Souza (2010), "Availability analysis of heat recovery steam generators used in thermal power plants", Energy 36 (2011) 3855e3870.
[11] Fink O. (2013),"Predicting component reliability and level of degradation with complex-valued neural networks", Reliability Engineering and System Safety 121 (2014) 198–206.
[12] Garg Savita, Jai Singh, D.V.Singh (2009),"Availability analysis of crank-case manufacturing in a two-wheeler automobile industry", Applied Mathematical Modeling 34 (2010) 1672–1683.
[13] GuYingkui and Li Jing (2012),"Multi-State System Reliability: A New and Systematic Review", Reliability Engineering(2ee0r1i1n)g 02090 (–2000102) 531 – 536.
[14] Guo and Yang (2008), "Automatic creation of Markov models for reliability assessment of safety instrumented systems", Reliability Engineering & System Safety, Volume 93, Issue 6, June 2008, Passages 829–837.
[15] Gurler and Kaya (2008), "A maintenance policy for a system with multi-state component: an approximate solution", Reliability Engineering & System Safety 76(2): 117-127.
[16] Huang and Yuan (2013), "A dynamic opportunistic maintenance policy for continuously monitored systems". Trans. J. of Quality Management Engineering, Volume 12, No. 3, 294 – 305.
[17] J.-J. Wang, Chao Fu, Kun Yang, Xu-Tao Zhang, Guo-hua Shi, John Zhai (2013),"Reliability and availability analysis of redundant BCHP (building cooling, heating and power) system", Energy 61 (2013) 531e540.
[18] J.W. Sun, Li-feng Xi, Shi-chang Du, Bo Ju(2008),"Reliability modeling and analysis of serial-parallel hybrid multioperational manufacturing system considering dimensional quality, tool degradation and system configuration", International Journal Production Economics 114, 149–164.
[19] L. Sikos, J. Klemes (2009), "Reliability, availability and maintenance optimization of heat exchanger networks", Applied Thermal Engineering.
[20] M. Colledani and A. Yemane (2013), "Impact of machine reliability data uncertainty on the design and operation of manufacturing systems", Forty Sixth CIRP Conference on Manufacturing Systems 2013, Procedia CIRP 7 (2013) 557 – 562.
[21] Mahmood M. (1987), "Development of performance evaluation system for screening unit of paper plant", International Journal of Industrial Engineering, 14(3), 220-225.
[22] Mahmood Reza Haghifam, MoeinManbachi (2010), "Reliability and availability modelling of combined heat and power (CHP) systems", Electrical Power and Energy Systems 33, 385–393.
[23] N.S. Sisworahardjo,M.S. Alam, G. Aydinli (2007), "Reliability and Sensitivity Analysis of Low Power Portable Direct Methanol Fuel Cell", 10.1109/EURCON.2007.4400616. The International Conference on "Computer as a Tool.
[24] Omran Musa Abbas, Hassan Ibrahim Mohammed and El NougomiAbdelgadir Omer (2011), "Development of Predictive Markov-chain Condition – Based Tractor Failure Analysis Algorithm", Research Journal of Agriculture and Biological Sciences, 7(1): 52-67, 2011.
[25] Rajiv Khanduja , P. C. Tewari, R.S. Chauhan (2009),"Performance Analysis of Screening Unit in a Paper Plant Using Genetic Algorithm", Journal of Industrial and Systems EngineeringVolume 3, No. 2, pp 140-151.

[26] ReshamVinayak and S. Dharamraja (2012),"Semi-Markov Modeling Approach for Deteriorating Systems with Preventive Maintenance", International Journal of Performability Engineering Volume 8, No. 5, September 2012, pp. 515- 526
[27] Romulo I. Zequeira, Jose E. Valdes, Christophe Berenguer (2007), "Optimal buffer inventory and opportunistic preventive maintenance under random production capacity availability", International Journal of Production Economics 02/2008; 111(2):686-696.
[28] Shakuntla, A.K.Lal, S.S.Bhatia (2002), "Availability Analysis of Polytube Industry When Two Sub-System Are Simultaneous Fail", Bangladesh Journal of Scientific and Industrial Research ISSN 0304-9809, Volume 46, No 4 (2002), BJSIR 2011; 46(4): 475-480.
[29] Sharma S. P.(2011),"Reliability analysis of complex multi-robotic system using GA and fuzzy methodology", Applied Soft Computing 12 (2012) 405–415.
[30] Singh (1991), "A new algorithm for multi-area reliability evaluation—Simultaneous decomposition-simulation approach", Electric Power Systems Research, Volume 21, Pages 129–136.
[31] Wu and Chan (2003), "Performance utility-analysis of multi-state systems", Ieee Transactions on Reliability, 2003, v. 52 n. 1, p. 14-21.