

e-ISSN: 2319-8753 | p-ISSN: 2347-6710

TEDIA

International Journal of Innovative Research in SCIENCE | ENGINEERING | TECHNOLOGY

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 7, July 2022

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

## Impact Factor: 8.118

9940 572 462

6381 907 438

 $\bigcirc$ 



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

Volume 11, Issue 7, July 2022

DOI:10.15680/IJIRSET.2022.1107078

## Reliability and Availability Analysis of Degrading Systems under Imperfect Repair Scenario using Markov Chain analysis

Udit Kitchlu<sup>1</sup>, Saransh Gupta<sup>2</sup>, Sarthak Singh<sup>3</sup>

U.G. Student, Department of Production and Industrial Engineering, Delhi Technological University, Delhi, India<sup>[1-2]</sup>

U.G. Student, Department of Mathematical Computation, Delhi Technological University, Delhi, India<sup>3</sup>

**ABSTRACT:** In this paper, mathematical models for the availability of a degrading system under imperfect repair scenarios with opportunistic maintenance are produced, which is based on the Markov Model. Mechanical systems, in general, weaken steadily before failing catastrophically. As a result, it would be more appropriate to model multi-state degradation and take appropriate maintenance action in the event of a system breakdown. Because it can include repair and other dependent elements in the model, the Markov technique is used for modelling and analysis of decaying systems. Two mechanical sub-system in series configuration are used to show the proposed technique. The gain in steady-state system availability is examined in this series configured system. The proposed model shows that if some portion of the machine requires maintenance by adopting Opportunistic Maintenance, we may boost the availability of a machine by a significant margin. When using corrective Maintenance at the same time, the availability is reversed. And it demonstrates that throughout the course of a 50,000-hour mission, the machine's time availability increases significantly.

KEYWORDS: Markov Analysis, Opportunistic Maintenance, Analysis of Decaying Systems.

#### **I.INTRODUCTION**

In these global and modern times, every industry is striving hard to keep up with customer demands with the ultimate objective of producing quality products and their timely delivery. So, each industry is investing in sophisticated machines that will help them in achieving their objectives. A mechanical system is a collection of physical components that convert motion and force from an input source into the desired output motion and force. At least three elements make up mechanical systems: input, process, and output. Any form of motion or force that drives the mechanical system is the input element of the system. But it also comes with a drawback, i.e with increase in complexity the risk of failure increases. A device's dependability is high if it has consistently performed its function well, and low if it has tended to fail in repeated trials. The probability that a system is operational at a particular moment, i.e. the amount of time a device is actually working as a fraction of thetotal time it should be operating, is known as availability. The availability of high- availability systems can be measured in minutes or hours of downtime per year. Even when failures occur, availability features allow the system to continue to function. The faulty element of a highly available system would be disabled, and the system would continue to operate at a reduced capacity. A less capable machine, on the other hand, may crash and become completely unusable. The chance of a system executing the intended function for a specific period of time under specified operating conditions is characterized as its reliability. Reliability engineering has become one of the most essential tools for increasing productivity and predicting when the system is going to fail. As we all know failures can occur in these machines due to various unknown reasons and we can know whether we have to change the complete system or just perform a repair on it by using the analysis of this technique. So the primary idea is to make the system run at least for the time it was designed to work, and opportunistic maintenance is used to improve system performance by analyzing degrading systems. To begin, each physical asset is deployed to perform a specified function or duties, As a result, when we maintain an asset, the state we want to keep it in must be one where it can continue to perform its intended functions. As a result, we arrive at a definition of maintenance in the "Traditional" sense: Maintaining physical assets to ensure that they continue to perform their intended tasks. Opportunistic maintenance is a systematic way of gathering, investigating, preplanning, and publicizing a list of planned maintenance activities, then acting on them when an unscheduled failure or repair "opportunity" arises. It has two benefits over traditional maintenance i.e. Reduced down time cost and savings of setup cost. Breakdown maintenance, also known as fire- fighting maintenance, failure maintenance, or



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

#### Volume 11, Issue 7, July 2022

#### | DOI:10.15680/IJIRSET.2022.1107078 |

corrective maintenance, was traditionally utilized in power plants. Breakdown maintenance can only be performed after a component or machine has failed. Breakdown maintenance is frequently accepted in power plants by default, and as a result, it is costly. It is critical for a power system to function as intended, but due to the unexpected nature of component failure, consumers cannot be guaranteed a continuous supply. Nowadays, more and more industries are considering opportunistic maintenance over traditional maintenance due to the major advantages opportunistic maintenance have over traditional maintenance. In this paper we have considered Imperfect repair as a maintenance action, it means that the subsystem in which any component has either reached the degraded or failed state cannot come back to the original operating state that was at time (t=0). This means that it will make a system not "as good as new" but younger. To find out what state it may reach we can define a factor called the Restoration factor (RF) with values ranging from 0 and 1. An RF equal to 0 indicates that no change takes place after the maintenance action, while an RF equal to 1 indicates that the component is repaired to a condition that is as good as new. But we all know that the Rf factor can never be equal to. Therefore, its value lies between 0 and 1 in practical usage. The remaining paper is structured as follows. Section 2 contains literature reviews. Section 3 describes Markov approaches. Section 4 defines the solution of differential equations. Section 5 contains graphs. Finally, section 6 concludes our work.

#### **II. RELATED WORK**

[1]takes into account safety, benefits, and maintenance loss characteristics. The proposed model resulted in lower maintenance costs and a lower risk of failure. For multi-unit series systems, [2]proposed an opportunistic preventive maintenance scheduling algorithm. The advantages of this strategy over individual maintenance and simultaneous maintenance were compared and presented using numerical simulations.[3]created an analytical model to quantify the degree of interacting failures between system components. The investigation was carried out bycalculating the system's Interactive Coefficient (IC). The bigger the IC value, the greater the impact of one component's failure on others.[4]proposed an approach for improving mechanical system dependability, availability, and maintainability. Failure mode analysis of mechanical systems utilizing Row Addition and K Clustering has been established using this methodology, which is based on many factors suchas function, structure, and failure mode. The majorgoal of this process is to create a design that is freeof errors.[5]developed a novel FMEA technique called "LifeCost Based FMEA," which solves many of the traditional FMEA's limitations and difficulties. Thistechnique measures risk of failures in terms of cost. The proposed technique calculates the costs of a system's lifecycle, including component failures during design, manufacturing, installation, and operation.[6]introduced a statistical modelling methodology that may be used to do both diagnostic and prognosis in a single framework. The Hidden SemiMarkov Model is used in this methodology (HSMM). In this study, this technology is utilized to monitor the health of hydraulic pumps. The results of this study show that HSMM-based diagnosis is superior to HMM-based diagnosis.[7]created a model to investigate failures caused by external shock and multifunctional failures. The catastrophic failure is studied using the shock model. To verify the model's results, a mechanical lock system was employed.[8]provide an approach for fault tolerant systems availability analysis and cost optimization. Numerous numerical tests were carried out to illustrate the system's behavior for various repairtime distributions. Bulk failure, general failure distribution, and optimal control strategy are all issues that can be considered in this study.[9]conducted a mechanical reliability study in 1983. Basic failure modes related to physical degradation are covered, as well as the supplementary data needed to link them to mechanical reliability. To increase our understanding of the relationship between material degradation and operating reliability, more researchis needed.

#### **III. METHODOLOGY**

#### Markov Model

The Markov model is defined as the function f(x,t) that is dependent on the state of the system (x) and the time of observation (t). Consider the following state space stochastic process: Xn, n=1,2,3. That has infinite number of possible values, where each state represents a different condition of system. If Xn=i, the system is said to be in state i at time n, and if the process is in state i there is a probability pij that it will be in state j at time n, and this stochastic process is known as a Markov chain. Toput it another way, the Markov model is a stochastic process that uses the probabilities of the present state to compute the probability of the future state. This method necessitates the existence of possible states, their paths, and their transition probabilities. Its diagram is made up of nodes that represent the states in which it exists and arrows that describe the paths and probability of reaching that system. These models are used to analyze systems that haveredundancy, interdependence, complex maintenance strategies, and/or failures that occur ina sequential order. For instance, if we need to compute the probability of the P2 state, we may do so if we already know the probabilities of the P1 state (P1 state is preceding the P2 state). Markov methods are employed in a wide range of



e-ISSN: 2319-8753, p-ISSN: 2320-6710 www.ijirset.com | Impact Factor: 8.118

Volume 11, Issue 7, July 2022

#### | DOI:10.15680/IJIRSET.2022.1107078 |

applications, including electro-power generation, process industry, and computer systems. After obtaining the initial condition using a diagram, we can solve the Markov model using one of two ways. [1] Solving Markov using matrix method [2] Solving Markov using differentialEquations

#### Using Markov analysis (matrix method)

This method is used to determine market penetration. If there are three brands, A, B, and C, and they want to know what percentage of their customers they will be able to retain and what theirfinal market penetration will be, they can use Markov analysis to predict. In this strategy, they only need to determine the present likelihood of customers who are loyal to that brand as well as the probabilities of switchingfrom the original brand to another brand, i.e.





PAA=probability of customers that are loyal tobrand A

PAC=Probability of customers that shifted from A toC,

PAB=Probability of customers that shifted from A toB

PBA=Probability of customers that shifted from B toA

PBB=Probability of customers that are loyal tobrand B

PBC= Probability of customers that shifted from Bto C,

PCA= Probability of customers that shifted from Cto A,

PCB= Probability of customers that shifted from Cto B,

PCC= Probability of customers that are loyal to brand C

Now we just need to figure out the probability for other brands in the same way and form a matrix. This matrix is the initial state matrix and from this stage, we can find out the probabilities of the nextstage using the formula X1=PX0 where X0 is the initial number of customers of every particular brand. Similarly X = P, X can be found out until PXn=Xn and this is the state where the process needs to be stopped and we have obtained the transition matrix. We will do this process several times till we obtain the state where PXn=Xn and this state is called transition state or stable state. Now while solving this we have to make two assumptions.



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

Volume 11, Issue 7, July 2022

#### | DOI:10.15680/IJIRSET.2022.1107078 |

[1] The matrix needs to be stochastic i.e. any square matrix with non-negative entries and row sum (PAA+PAB+PAC+PAD=1) equal to unity. [2] There will be a state where PXn=Xn and that state is called the transition matrix or stability matrix. After this value, you will see no change in the values of A, B, C

#### Using Markov analysis (Differential method)



This method is employed in reliability analysis when a collection of system components is linked in series. A Markov model requires possible states, transition pathways, and transition rate parameters, where each state reflects a different state of the system. To determine the system's reliability/availability, one has to form a set of linear differential equations  $\lambda$  - Transition rate from State 1 to State 2. $\lambda$  - Transition rate from State 1 to State 2.

Pi(t) - Probability of system being in  $i^{a}$  state at time t. From this we will get the differential equations for two state Markov model which is expressed as: -

$$\frac{\frac{dP_1(t)}{dt}}{\frac{dP_2(t)}{dt}} = -\lambda P_1(t)$$

 $P_1(t) + P_2(t) = 1$ 

The times between when a failure occurs and when a repair is done are random variables that follow an exponential distribution. The rates of these exponential distributions are  $\lambda$  known as the failure rate and  $\mu$  which is not mentioned in the diagram but is given when there is flow from 2 to 1 is known as the repair rate of component i , for i = 1, 2. This means

that the meantime to failure (MTTFi) of pump i is  $\overline{\lambda}$  and its mean repair time (MTTRi) is  $\overline{\mu}$ .Now, we can see that a huge number of components are there, and we can see that there are multiple differential equations that can be solved using Python.

#### **System Description**

We concentrated on analyzing reliability using differential equations in this research article.

We will consider a system formed by connecting two subsystems in series. Each subsystem can be in any one of the following state at a particular time:

- 1. O=New/operational state
- 2. D denotes a degraded state.
- 3. F=Failure condition



Picture 3



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

#### Volume 11, Issue 7, July 2022

State	component1	component2
1	0	0
2	0	D
3	D	0
4	0	F
5	F	0
6	D	F
7	F	D
8	D	D

#### DOI:10.15680/IJIRSET.2022.1107078

#### Table 1

The letters O and D represent working states, whereas the letters F represent failure states. They system will stop working if any of the subsystem is in failure state.

Because we have two components and each can be in three states, we have  $3^2=9$  potential states, but we will only consider eight of these because we have assumed that both systems cannot fail at the same time. Other assumptions we have made for this method are as follows:[1] Because the system includes two components connected in series, it is likely to fail even if one system fails. [2] Subsystems deteriorate gradually. [3] Inadequate repair returns the system to its degraded state. [4]The probability of the initial subsystem being 1 at t=0. [5] Imperfect repair of system is considered. Here, Imperfect repair means that a subsystem in which any component has degraded or failed cannot be restored to the original functioning state that existed at the time (t=0). This means that it will create a system that is not "as good as new," but rather younger. To determine what state it may achieve, we can create a number called the Restoration factor (RF), which has a value between 0 and 1. An RF of 0 implies that no change occurs after the maintenance procedure, whereas an RF

System State		Subsystem	Subsystem	Transition	C.M.
S. No.	Status	1	2	to	
1	Working	0	0	23	-
2	Working	0	D	4 5	-
3	Working	D	0	65	-
4	Repair	0	F	2	Yes
5	Working	D	D	78	-
6	Repair	F	0	3	Yes
7	Repair	D	F	5	Yes
8	Repair	F	D	5	Yes

Transition Diagram for C.M.

C.M. maintenance



Transition Diagram for C.M.

of 1 indicates that the component is repaired to as good as new condition. However, we all know that the Rf factor can never equal 1. As a result, in practice, its value ranges between 0 and 1.

The system starts in state 1 at time t = 0. It will gradually start degrading as time passes. When component 1 degrades the system goes to state 3 and when component 2 degrades it goes to state 2. It will go to state 8 when both the component degrades. Once a component reaches degraded state it, if further degrades and reaches failed state. In state 4, component 2 is in failed state, a maintenance action is done which restores the subsystem from its failed state to the degraded state and from degraded state to operating state respectively. From table 1, we can derive the following inferences that the combination of 2 components since connected in series will only work when neither of them is in a failed state.

Traditionally, only corrective maintenance was utilized, which was performed only when a failure occurred. In this work, however, we have included opportunistic maintenance as well. Opportunistic maintenance is also known as



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

#### Volume 11, Issue 7, July 2022

#### | DOI:10.15680/LJIRSET.2022.1107078 |

examining, calculating a set of duties, and then performing a maintenance activity during a repair opportunity. This is done to extend the life of a component or, at the very least, to delay the next failure whose repair may be costly, and to take advantage of the resources, efforts, and time that have already been expended in the process up to that point in order to save money. In layman's terms, it improves system availability by forecasting the failed condition and restoring it so that it may be made to work for a longer amount of time. This selection is now made with a few considerations in mind, such as – [1] The remaining life cost is the product of the number of hours or cycles left (RL) and the cost of the item (CI) per hour/cycle. [2] Downtime Expense- The cost incurred when a piece of equipment or machine is inoperable or unable to perform. Uptime cost- The expense incurred during a period of unanticipated failure fails, this system is inoperable. As a result, we can claim that four states require maintenance since one of the two components is in a failed condition (F). As a result, four of the eight possible states are in the process of being repaired

System Model based on imperfect repair without opportunistic maintenance  $\rightarrow$  Observing figure below, we can now describe the flow depicted in the diagram. Consider state 3, which defines D and O as states for the two subsystems. When the state changes to 6, component 1 becomes F while component 2 remains the same as before, i.e. in the operating(O) state. Because there is no opportunistic maintenance and if one component fails, the entire system

 $P_i(t)$  - Probability of system being in  $i^{th}P_i(t)$  - Probability of system being in  $i^{th}$  state at time t.  $\frac{dP_i(t)}{dt}$  - Rate of change of  $i^{th}$  state at time t.

 $\lambda_{ij}$ - Rate of degradation from state i to j.  $\mu_{ij}$ - Rate of repair from state i to j

The Markov differential equation is developed by giving the probability of each state at time  $t + \Delta t$  as a function of that state at time t.  $\Delta t$  is the time it stays in that state. The Probability of being in state 1 at some time  $t+\Delta t$  is equal to the probability of being in state 1 at time t and not transitioning out during time  $\Delta t$ . Thus, we get the equation,

$$P_{1}(t + \Delta t) = P_{1}(t)[1 - (\lambda_{12} + \lambda_{13})\Delta t]$$

From this we will get the differential equation-

$$\frac{dP_1(t)}{dt} = -P_1(t)(\lambda_{12} + \lambda_{13})$$

The probability of being in state 2 at time  $t+\Delta t$  is equal to the probability of being in state 1 at time t and transitioning to state 2 at time  $\Delta t$  and the probability of being in state 4 at time t and transitioning to state 2 at time  $\Delta t$  with the probability of being in state 2 at time t and not transitioning out during time  $\Delta t$ .

$$P_2(t + \Delta t) = P_1(t)\lambda_{12}\Delta t + P_4(t)\mu_{42}\Delta t + [1 - (\lambda_{24} + \lambda_{25})\Delta t]P_2(t)$$

This is Chapman-Kolmogorov Equations for Markov Process.

From this we will get the differential equation-

$$\frac{dP_2(t)}{dt} = P_1(t)\lambda_{12} + P_4(t)\mu_{42} - P_2(t)(\lambda_{24} + \lambda_{25})$$

Similarly,

$$\frac{dP_3(t)}{dt} = P_1(t)\lambda_{13} + P_6(t)\mu_{63} - P_3(t)(\lambda_{36} + \lambda_{35})$$
$$\frac{dP_4(t)}{dt} = P_2(t)\lambda_{24} - P_4(t)\mu_{42}$$

$$\frac{dP_5(t)}{dt} = P_7(t)\mu_{75} + P_8(t)\mu_{85} + P_2(t)\lambda_{25} + P_3(t)\lambda_{35} - P_5((t)(\lambda_{57} + \lambda_{58}))$$
$$\frac{dP_6(t)}{dt} = P_3(t)\lambda_{36} - P_6(t)\mu_{63}$$

state at time t.

IJIRSET © 2022



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

#### Volume 11, Issue 7, July 2022

 $\frac{dP_i(t)}{dt}$  Rate of change of  $i^{th}$  state at time t.  $\lambda_{ij}$ -Rate of degradation from state i to j.  $\mu_{ij}$ -Rate of repair from state i to j

The Markov differential equation is developed by giving the probability of each state at time  $t + \Delta t$  as a function of that state at time t.  $\Delta t$  is the time it stays in that state. The Probability of being in state 1 at some time  $t+\Delta t$  is equal to the probability of being in state 1 at time t and not transitioning out during time  $\Delta t$ . Thus, we get the equation,  $\Rightarrow P_1(t + \Delta t) = P_1(t)[1 - (\lambda_{12} + \lambda_{13})\Delta t]$ . From this we will get the differential equation  $\Rightarrow \frac{dP_1(t)}{dt} = -P_1(t)(\lambda_{12} + \lambda_{13})$ . The probability of being in state 2 at time  $t + \Delta t$  is equal to the probability of being in state 1 at time t and transitioning to state 2 at time  $\Delta t$  and the probability of being in state 4 at time t and transitioning to state 2 at time  $\Delta t$  with the probability of being in state 2 at time t and not transitioning out during time  $\Delta t$ .

$$P_2(t + \Delta t) = P_1(t)\lambda_{12}\Delta t + P_4(t)\mu_{42}\Delta t + [1 - (\lambda_{24} + \lambda_{25})\Delta t]P_2(t)$$

This is Chapman-Kolmogorov Equations for Markov Process.

From this we will get the differential equation  $- \frac{dP_2(t)}{dt} = P_1(t)\lambda_{12} + P_4(t)\mu_{42} - P_2(t)(\lambda_{24} + \lambda_{25})$ 

Similarly,

$$\frac{dP_{3}(t)}{dt} = P_{1}(t)\lambda_{13} + P_{6}(t)\mu_{63} - P_{3}(t)(\lambda_{36} + \lambda_{35})$$
$$\frac{dP_{4}(t)}{dt} = P_{2}(t)\lambda_{24} - P_{4}(t)\mu_{42}$$
$$\frac{dP_{5}(t)}{dt} = P_{7}(t)\mu_{75} + P_{8}(t)\mu_{85} + P_{2}(t)\lambda_{25} + P_{3}(t)\lambda_{35} - P_{5}((t)(\lambda_{57} + \lambda_{58}))$$
$$\frac{dP_{6}(t)}{dt} = P_{3}(t)\lambda_{36} - P_{6}(t)\mu_{63}$$
$$\frac{dP_{7}(t)}{dt} = P_{5}(t)\lambda_{57} - P_{7}(t)\mu_{75}$$
$$\frac{dP_{8}(t)}{dt} = P_{5}(t)\lambda_{58} - P_{8}(t)\mu_{85}$$

System Model based on imperfect repair with opportunistic maintenance  $\rightarrow$  Now observing this table, we can describe what is happening in the process and how O.M. (opportunistic maintenance) is helping us. Whenever system is under repair, opportunistic maintenance action takes place if there is a system in degraded state. Two lines which represent imperfect repair only and no O.M. i.e. restoring the system from f to D are removed i.e. 7-5 and 8-5. New lines 7-2 and 8-3 representing imperfect repair coupled with O.M. are included in this model. In this system we observe that after applying opportunistic maintenance we get two more available systems and therefore that the number of available systems are increasing and we are able to decrease the maintenance cost and the time.

System State		Subsystem Su 1	Subsystem 2	Transition to	Maintenance Possibility	
S. No.	Status				C.M.	0.M
1	Working	0	0	23	-	19 <b>4</b> 0
2	Working	0	D	4 5	-	19 <u>1</u> 0
3	Working	D	0	65	-	-
4	Repair	0	F	2	Yes	No
5	Working	D	D	78	-	
6	Repair	F	0	3	Yes	No
7	Repair	D	F	2	Yes	Yes
8	Repair	F	D	3	Yes	Yes





| e-ISSN: 2319-8753, p-ISSN: 2320-6710| www.ijirset.com | Impact Factor: 8.118|

Volume 11, Issue 7, July 2022

| DOI:10.15680/IJIRSET.2022.1107078 |

Differential equations:

$$\frac{dP_1(t)}{dt} = -(\lambda_{12} + \lambda_{13})$$

$$\frac{dP_2(t)}{dt} = P_1(t)\lambda_{12} + P_4(t)\mu_{42} + P_7(t)\mu_{72} - P_2(t)(\lambda_{24} + \lambda_{25})$$

$$\frac{dP_3(t)}{dt} = P_1(t)\lambda_{13} + P_6(t)\mu_{63} + P_8(t)\mu_{83} - P_3(t)(\lambda_{36} + \lambda_{35})$$

$$\frac{dP_4(t)}{dt} = P_2(t)\lambda_{24} - P_4(t)\mu_{42}$$

$$\frac{dP_5(t)}{dt} = P_2(t)\lambda_{25} + P_3(t)\lambda_{35} - P_5((t)(\lambda_{57} + \lambda_{58}))$$

$$\frac{dP_6(t)}{dt} = P_3(t)\lambda_{36} - P_6(t)\mu_{63}$$

$$\frac{dP_7(t)}{dt} = P_5(t)\lambda_{57} - P_7(t)\mu_{72}$$

$$\frac{dP_8(t)}{dt} = P_5(t)\lambda_{58} - P_8(t)\mu_{83}$$

Once the probabilities of the states have been obtained, the stability probability of the system in state i can be calculated by

$$p_i = \lim_{t \to \infty} P_i(t), i = 1, 2, \dots, 8$$

The Availability of the System at time t is the sum of all working state probabilities,

$$A(t) = P_1(t) + P_2(t) + P_3(t) + P_5(t)$$



Probability	T1	T2	T3	T4	T5
P1	1.00000000e+	9.98610827e-	9.97223583e-	9.25219511e-	9.23936954e-
	00	01	01	07	07
P2	0.00000000e+	5.54053335e-	1.10610952e-	5.51881834e-	5.51333134e-
	00	04	03	05	05
P3	0.00000000e+	8.29329853e-	1.64724473e-	8.22075185e-	8.20935650e-
	00	04	03	08	08
P4	1.00000000e+	9.98610827e-	9.97223583e-	9.24969141e-	9.23683148e-
	00	01	01	07	07
P5	0.007	0.00055405	0.00110611	0.40201801	0.40201801
P6	0.0004	0.00082933	0.00164724	0.05365127	0.05365127
P7	0.00000000e+	6.06672512e-	2.40909844e-	7.16001044e-	7.16001044e-
	00	07	06	03	03

Table 2: Probabilities of different states at time T

Availability of system



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| <u>www.ijirset.com</u> | Impact Factor: 8.118|

#### Volume 11, Issue 7, July 2022

#### | DOI:10.15680/IJIRSET.2022.1107078 |

**Solution of Differential Equation** The nature of the above system can be expressed in terms of availability and reliability. This can be evaluated by solving the differential equations. Availability is often greater than reliability. The system of equations with corrective maintenance and opportunistic maintenance are solving using python libraries for a mission time of 5\*104 hrs. It is known that system will only be in state 1 in both the cases at time t=0. The results obtained is shown in the Graph 1. The blue line represents imperfect repair without opportunistic maintenance whereas the red line represents imperfect repair with opportunistic maintenance. This graph clearly shows the improvement in system performance when opportunistic maintenance is applied. Table 2 and graph 2 shows us how the system is more likely to be found in the failed or degraded state as time passes and it is unlikely for the system to be in state 1

#### **IV. CONCLUSION**

In this study, Markov approach has been proposed for reliability and availability analysis of degrading systems. The research involves degradation-based modelling, the derivation of transitions of each feasible state, and the solution of system model for reliability and availability assessment. The suggested method is demonstrated for a mechanical system containing two subsystems in series. In this series configured system, the gain in steady-state system availability is evaluated. The findings indicate that when opportunistic maintenance is utilized, there is gain in availability. The state of the machine is considered among three of the states that is operating state (O) Degraded state (D) Failed state(F). If some part of the machine is under condition of maintenance through this paper, we have concluded that using Opportunistic Maintenance we could increase the availability of a machine by many folds. Whereas at the same time using Normal Maintenance/Corrective Maintenance the availability is vice a versa. This is further concluded using Markov Chain Analysis.





#### REFERENCES

- 1. Hu, Jinqiu & Zhang, Laibin. (2014). Risk based opportunistic maintenance model for complex mechanical systems. Expert Systems with Applications: An International Journal. 41. 3105-3115. 10.1016/j.eswa.2013.10.041.
- 2. "Opportunistic preventive maintenance scheduling for a multi-unit series system based on dynamic programming."
- 3. INFONA science communication portal
- 4. Sun, Yong & Ma, Lin & Mathew, Joseph & Zhang, Sheng, 2006. "An analytical model for interactive failures," Reliability Engineering and System Safety, Elsevier, vol. 91(5), pages 495-504.
- Wani, MF, & Jan, M. "Failure Mode Analysis of Mechanical Systems at Conceptual Design Stage." Proceedings of the ASME 8th Biennial Conference on Engineering Systems Design and Analysis. Volume 1: Advanced Energy Systems, Advanced Materials, Aerospace, Automation and Robotics, Noise Control and Acoustics, and Systems Engineering. Torino, Italy. July 4-7, 2006. pp. 985-995. ASME.
- Rhee, SJ, & Ishii, K. "Life Cost-Based FMEA Incorporating Data Uncertainty." Proceedings of the ASME 2002 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 3: 7th Design for Manufacturing Conference. Montreal, Quebec, Canada. September 29-October 2, 2002. pp. 309-318. ASME.



| e-ISSN: 2319-8753, p-ISSN: 2320-6710| www.ijirset.com | Impact Factor: 8.118|

Volume 11, Issue 7, July 2022

| DOI:10.15680/IJIRSET.2022.1107078 |

- 7. Ming Dong and David He, (2007), Hidden semi-Markov model-based methodology for multi-sensor equipment health diagnosis and prognosis, European Journal of Operational Research, 178, (3),858-878
- 8. Liu, J., Song, B. and Zhang, Y. (2018) 'Competing failure model for mechanical system with multiple functional failures', Advances in Mechanical Engineering.
- 9. Jain, M., Kumar Meena, R. (2018). 'Vacation model for Markov machine repair problem with two heterogeneous unreliable servers and threshold recovery', Journal of Industrial Engineering International, 14(1)
- 10. P. Martin, J.E. Strutt, N. Kinkead, A review of mechanical reliability modelling in relation to failure mechanisms, Reliability Engineering, Volume 6, Issue 1,1983, Pages 13-42, ISSN 0143-8174





Impact Factor: 8.118





## INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY





www.ijirset.com