PERFORMANCE MODELING AND DSS FOR ASSEMBLY LINE SYSTEM OF LEAF SPRING MANUFACTURING PLANT

Shanti Parkash

•

Ph.D. Scholar, Department of Production and Industrial Engineering, National Institute of Technology, Kurukshetra-136119, INDIA, Shanti_62000012@nitkkr.ac.in

P.C.Tewari

•

Professor, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra-136119, INDIA, pctewari1@gmail.com

Abstract

This work deals with the Performance Modelling and purposed the Decision Support System (DSS) for maintenance priorities of an assembly line system using a probabilistic approach. This system consists of four subsystems i.e. Shot Peening, Painting Machine, Assembly Platform and Riveting Machine. Performance modelling among various subsystems has been done by Markovian approach. Steady state probabilities are determined by drawing transition diagram and solving the differential equations. Decision matrices are formed with the help of different combinations of failure and repair rates of all the subsystems. The key finding of this work is that painting machine is the most critical subsystem.

Keywords: Markovian Approach, Availability, DSS, Reliability, Maintainability, Performability, RAMS.

I. Introduction

Automobile sector becomes a driver for the growth of a country like India. Leaf springs are the important part of vehicle suspension system which support the overall weight of the vehicle and help to maintain a safe and comfortable ride. Leaf spring manufacturing plants have usually very complex systems in their higher production units. The maintenance of these complex systems becomes costly and time consuming in today's industrial scenario. These challenges have now taken by engineers as an opportunity. An appropriate decision can reduce the operating as well as maintenance costs and also improves the performability of the system. Performability of the plant reduces when the system becomes unavailable for longer period of time. Reliability, Availability, Maintainability and Safety (RAMS) approach plays a significant role to take better and quick decisions in a proper time frame. This is a four dimensional approach which can helps both engineers and managers to enhance the performability of the system by utilizing the best combination of failure and repair rates. RAMS reduces the cost of the plant which helps to achieve the breakeven point rapidly. DSS has been developed using various statistical based techniques such as Reliability Hazard Analysis, Failure Mode and Effects Analysis (FMEA), Reliability Block Diagram, Root Cause Analysis, Fault Tree Analysis, Finite Element Analysis, Markov Analysis, Petri Nets etc.

In this work, Markovian approach has been used for performance modeling and analysis of the system. Markov birth-death analysis is used to predict a random variable, based upon the current state not on the previous activities. It defines the future action on the basis of the current state of a variable. In engineering, this approach has been used to predict the performability of system on the basis of their current state. The probability of any variable has been determined by a decision tree, called transition diagram.

II. Literature Review

Over the past decade, many researchers using this markovian approach for performance modeling of different complex systems. Zhang and Cao [1] determined the reliability of a heat exchanger in deep-sea submersibles using Markov analysis method. Jiang et al. [2] applied Markov chain method on the measured sensors to get their reliability degradation over time in drilling machines. Salari and Makis [3] proposed a modelling for a multi-unit production system using Markov renewal theory. Galagedarage and Khan [4] introduced a methodology which detect and diagnosis the fault using hidden markovian method. Malik and Tewari [5] had done the performance modelling for the Water Flow System (WFS) of a thermal power plant. Alizadeh and Srinivas [6] developed a reliability redundant model for safety systems using markov method. Hassan et al. [7] purposed a stochastic model for liquefied natural gas plant using Markov analysis. Shichang et al. [8] developed a Markov model for multistage manufacturing plant for performance analysis. Kumar [9] had done availability analysis of air circulation system of a thermal plant by markov modelling. Liu et al. [10] discussed double 2-out-of-2 system to obtained time dependent safety and reliability of the system. Kumar et al. [11] evaluated the availability of a thermal power plant using markov birth-death technique. Vora and Tewari [12] described stochastic modelling and analysis of condensate system of a thermal plant using markovian approach. Ge and Asgarpoor [13] developed algorithm for reliability evaluation of equipment with fuzzy markov model.

III. System Description

Assembly line system of a leaf spring manufacturing plant has four major subsystems: Shot Peening (A), Painting Machine (B), Assembly Platform(C) and Riveting Machine (D). Out of these subsystems, only painting machine subsystem has 4 lines in parallel arrangement. Failure of any line of this subsystem reduces the capacity of the system. Other subsystems have no provision of redundancy.

The nomenclatures used for the subsystems (as shown in fig. 1) are described as:

A, B, C and D	: Represent all subsystems are operating in full capacity.
B′, B′′, B′′′	: Represent subsystem B is operating in reduces capacity.
a, b, c and d	: Represent the failure state of all subsystems.
λ_i, i=1,2,3,4	: Mean constant failure rates for different subsystems A,B, C and D respectively.
μ_i, i =1, 2, 3, 4	: Mean constant repair rates for different subsystems A, B, C and D respectively.
$P_j(t)$, j= 0,1,2……19	: Probability at time ‘t’ the system is in j^{th} state

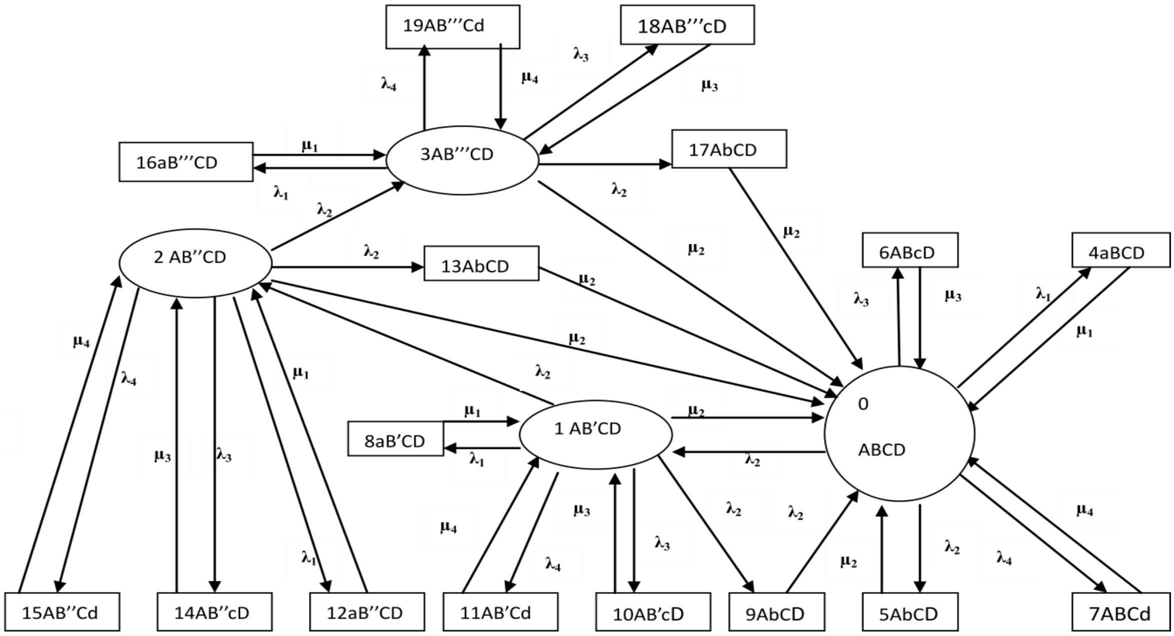

Fig 1: *Transition Diagram of Assembly Line System*

This transition diagram shows the total 20 states ('0' to '19') out of which state '0' represents the full capacity operation, 3 states (i.e., '1' to '3') represents the reduced capacity operation, while 15 states (i.e., '4' to '19') represents the failure state in the transition diagram.

IV. Performance Modelling of the Assembly Line System

To determine the performability of an assembly line system of a Leaf spring manufacturing plant, the mathematical formulation has been carried out using mnemonic rule for all the subsystems. Following mathematical equations represent the two states of the system, transient and steady states.

I. Transient State

The following first order differential equations associated with the transition diagram of the system at time $(t+\Delta t)$:

$$P_0(t+\Delta t) - P_0(t) = [-\lambda_1\Delta t - 2\lambda_2\Delta t - \lambda_3\Delta t - \lambda_4\Delta t]\, P_0(t) + \mu_1\Delta t P_4(t) + \mu_2\Delta t\, \{P_1(t) + P_2(t) + P_3(t) + P_5(t) + P_9(t) + P_{13}(t) + P_{17}(t)\} + \mu_3\Delta t P_6(t) + \mu_4\Delta t P_7(t)]$$

Taking $\Delta t \to 0$, we get:

$$P'_0(t) = -X_0P_0(t) + \mu_1\Delta t P_4(t) + \mu_2\Delta t\, \{P_1(t) + P_2(t) + P_3(t) + P_5(t) + P_9(t) + P_{13}(t) + P_{17}(t)\} + \mu_3\Delta t\, P_6(t) + \mu_4\Delta t P_7(t)$$

$$P'_0(t) + X_0P_0(t) = \mu_1\Delta t P_4(t) + \mu_2\Delta t\, \{P_1(t) + P_2(t) + P_3(t) + P_5(t) + P_9(t) + P_{13}(t) + P_{17}(t)\} + \mu_3\Delta t\, P_6(t) + \mu_4\Delta t\, P_7(t) \quad (1)$$

Similarly,

$$P'_1(t) + X_1P_1(t) = \lambda_2P_0(t) + \mu_1P_8(t) + \mu_3P_{10}(t) + \mu_4P_{11}(t) \quad (2)$$

$P'_2(t) + X_1P_2(t) = \lambda_2P_1(t) + \mu_1P_{12}(t) + \mu_3P_{14}(t) + \mu_4P_{15}(t)$ (3)

$P'_3(t) + X_2P_3(t) = \lambda_2P_2(t) + \mu_1P_{16}(t) + \mu_3P_{18}(t) + \mu_4P_{19}(t)$ (4)

Where

$X_0 = \lambda_1 + 2\lambda_2 + \lambda_3 + \lambda_4$

$X_1 = \lambda_1 + 2\lambda_2 + \lambda_3 + \lambda_4 + \mu_2$

$X_2 = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \mu_2$

$P'_i(t) + \mu_j P_i(t) = \lambda_jP_0(t)$, where, i = 4, 5, 6, 7; j = 1, 2, 3, 4 (5)

$P'_i(t) + \mu_j P_i(t) = \lambda_jP_1(t)$, where, i = 8, 9, 10, 11; j = 1, 2, 3, 4 (6)

$P'_i(t) + \mu_j P_i(t) = \lambda_jP_2(t)$, where, i = 12, 13, 14, 15; j = 1, 2, 3, 4 (7)

$P'_i(t) + \mu_j P_i(t) = \lambda_jP_3(t)$, where, i = 16, 17, 18, 19; j = 1, 2, 3, 4 (8)

II. Steady State

Steady state probabilities of the system are obtained by imposing the following restriction: as $t\rightarrow\infty$, $d/dt\rightarrow 0$.Final results for long run availability are obtained from steady state.

In this state, equation (1) to (8) reduced to the following system of equations:

$X_0P_0 = \mu_1P_4 + \mu_2(P_1 + P_2 + P_3 + P_5 + P_9 + P_{13} + P_{17}) + \mu_3P_6 + \mu_4P_7$ (9)

Similarly,

$X_1P_1 = \lambda_2P_0 + \mu_1P_8 + \mu_3P_{10} + \mu_4P_{11}$ (10)

$X_2P_2 = \lambda_2P_1 + \mu_1P_{12} + \mu_3P_{14} + \mu_4P_{15}$ (11)

$X_2P_3 = \lambda_2P_2 + \mu_1P_{16} + \mu_3P_{18} + \mu_4P_{19}$ (12)

$\mu_jP_i = \lambda_jP_0$, where, i = 4, 5, 6, 7; j = 1, 2, 3, 4 (13)

$\mu_jP_i = \lambda_jP_1$, where, i = 8, 9, 10, 11; j = 1, 2, 3, 4 (14)

$\mu_jP_i = \lambda_jP_2$, where, i = 12, 13, 14, 15; j = 1, 2, 3, 4 (15)

$\mu_jP_i = \lambda_jP_3$, where, i = 16, 17, 18, 19; j = 1, 2, 3, 4 (16)

By solving these equations, we get

Where $N_1= \lambda_1/\mu_1$, $N_2= \lambda_2/\mu_2$, $N_3= \lambda_3/\mu_3$, $N_4= \lambda_4/\mu_4$

$P_{19} = N_4P_3 = N_4(\lambda_2/2\lambda_2+\mu_2)^2(\lambda_2/\lambda_2+\mu_2)P_0$,

$P_{18} = N_3P_3 = N_3(\lambda_2/2\lambda_2+\mu_2)^2(\lambda_2/\lambda_2+\mu_2)P_0$,

$P_{17} = N_2P_3 = N_2(\lambda_2/2\lambda_2+\mu_2)^2(\lambda_2/\lambda_2+\mu_2)P_0$,

$P_{16} = N_1P_3 = N_1(\lambda_2/2\lambda_2+\mu_2)^2(\lambda_2/\lambda_2+\mu_2)P_0$,

$P_{15} = N_4P_2 = N_4(\lambda_2/2\lambda_2+\mu_2)^2P_0$,

$P_{14} = N_3P_2 = N_3\ (\lambda_2/2\lambda_2+\mu_2)^2\ P_0,$

$P_{13} = N_2P_2 = N_2\ (\lambda_2/2\lambda_2+\mu_2)^2\ P_0,$

$P_{12} = N_1P_2 = N_1\ (\lambda_2/2\lambda_2+\mu_2)^2\ P_0,$

$P_{11} = N_4P_1 = N_4\ (\lambda_2/2\lambda_2+\mu_2)\ P_0,$

$P_{10} = N_3P_1 = N_3\ (\lambda_2/2\lambda_2+\mu_2)\ P_0,$

$P_9 = N_2P_1 = N_2\ (\lambda_2/2\lambda_2+\mu_2)\ P_0,$

$P_8 = N_1P_1= N_1\ (\lambda_2/2\lambda_2+\mu_2)\ P_0,$

$P_7 = N_4P_0,$

$P_6 = N_3P_0,$

$P_5 = N_2P_0,$

$P_4 = N_1P_0,$

$P_3 = (\lambda_2/\lambda_2+\mu_2)\ P_2 = (\lambda_2/\lambda_2+\mu_2)(\lambda_2/2\lambda_2+\mu_2)^2\ P_0,$

$P_2 = (\lambda_2/2\lambda_2+\mu_2)\ P_1 = (\lambda_2/2\lambda_2+\mu_2)^2\ P_0$

$P_1 = (\lambda_2/2\lambda_2+\mu_2)\ P_0$

Now under the normalizing condition, summation of all the state probabilities is equal to one,

$\Sigma\ P_i = 1$, i.e. $P_0+P_1+P_2+$..........................$+P_{19}=1$

We get from the above equations,

$$P_0 = [1 + (\lambda_2/2\lambda_2+\mu_2) + (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda_2/\lambda_2+\mu_2)\ (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda 1/\ \mu_1) + (\lambda_2/\ \mu_2)+ (\lambda_3/\ \mu_3)+ (\lambda_4/\ \mu_4)+ (\lambda 1/\mu_1)\ (\lambda_2/2\lambda_2+\mu_2) + (\lambda_2/\mu_2)\ (\lambda_2/2\lambda_2+\mu_2) + (\lambda_3/\mu_3)\ (\lambda_2/2\lambda_2+\mu_2) + (\lambda_4/\mu_4)\ (\lambda_2/2\lambda_2+\mu_2) + (\lambda 1/\mu_1)\ (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda_2/\mu_2)\ (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda_3/\mu_3)\ (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda_4/\mu_4)\ (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda 1/\mu_1)\ (\lambda_2/2\lambda_2+\mu_2)^2\ (\lambda_2/\lambda_2+\mu_2) + (\lambda_2/\mu_2)\ (\lambda_2/2\lambda_2+\mu_2)^2\ (\lambda_2/\lambda_2+\mu_2) + (\lambda_3/\mu_3)\ (\lambda_2/2\lambda_2+\mu_2)^2\ (\lambda_2/\lambda_2+\mu_2) + (\lambda_4/\ \mu_4)\ (\lambda_2/2\lambda_2+\mu_2)^2\ (\lambda_2/\lambda_2+\mu_2)\ ]^{-1}$$

The long run performability of the system in terms of availability A (∞) can now be determined using the following equation:

$$A\ (\infty) = P_0 + P_1 + P_2 + P_3 = P_0 + (\lambda_2/2\lambda_2+\mu_2)\ P_0 + (\lambda_2/2\lambda_2+\mu_2)^2\ P_0 + (\lambda_2/\lambda_2+\mu_2)\ (\lambda_2/2\lambda_2+\mu_2)^2\ P_0$$

$$= [1+ (\lambda_2/2\lambda_2+\mu_2) + (\lambda_2/2\lambda_2+\mu_2)^2 + (\lambda_2/\lambda_2+\mu_2)(\lambda_2/2\lambda_2+\mu_2)^2]\ P_0 \qquad (17)$$

Failure and repair data for study were obtained from the maintenance logbook of the plant. Failure and repair data follow the exponential distribution.

Table 1: *Failure and repair rates of assembly line system*

Name of the SUBSYSTEM	Exponential Distribution	
	Mean Failure Rate (λ)	Mean Repair Rate (μ)
SHOT PEENING	0.0003 (λ_1)	0.0050 (μ_1)
PAINTING MACHINE	0.0030 (λ_2)	0.0310 (μ_2)
ASSEMBLY	0.0002 (λ_3)	0.0076 (μ_3)
RIVETING	0.0030 (λ_4)	0.2000 (μ_4)

V. Results and Discussion

Table 2, 3, 4 and 5 represent the performability matrices for various subsystems of the assembly line system according to the best possible combinations of failure and repair rates of various subsystems. Tables and figs. 2 to 5 show the effect of failure and repair rates of Shot Peening, Painting Machine, Assembly Platform and Riveting Machine on the steady state performance of the system respectively. Table 2 and fig. 2 reveal the effect of various failure and repair rates of shoot peening on the performability of the system in the terms of availability while other parameters remain constant. As the failure rate increases from 0.0001 to 0.0005, the performability of the system decreases sharply from 0.8077 to 0.6105 (approx.20%) in terms of availability. Similarly, when the repair rate increases from 0.0010 to 0.0090, the performability of the system increases from 0.8077 to 0.8702 (approx. 8%) in terms of availability.

Table 2: *Effect of the failure and repair rates of shot peening subsystem on system performability (%)*

Failure Rates	Repair Rates of Shot Peening					Constant Parameters
	0.0010	0.0030	0.0050	0.0070	0.0090	
0.0001	0.8077	0.8537	0.8635	0.8678	0.8702	λ_2=0.0030
0.0002	0.7473	0.8300	0.8488	0.8571	0.8618	μ_2=0.0310
0.0003	0.6954	0.8077	0.8347	0.8468	0.8537	λ_3=0.0002
0.0004	0.6502	0.7865	0.8210	0.8367	0.8456	μ_3=0.0076
0.0005	0.6105	0.7664	0.8077	0.8268	0.8378	λ_4=0.0030 μ_4=0.2000

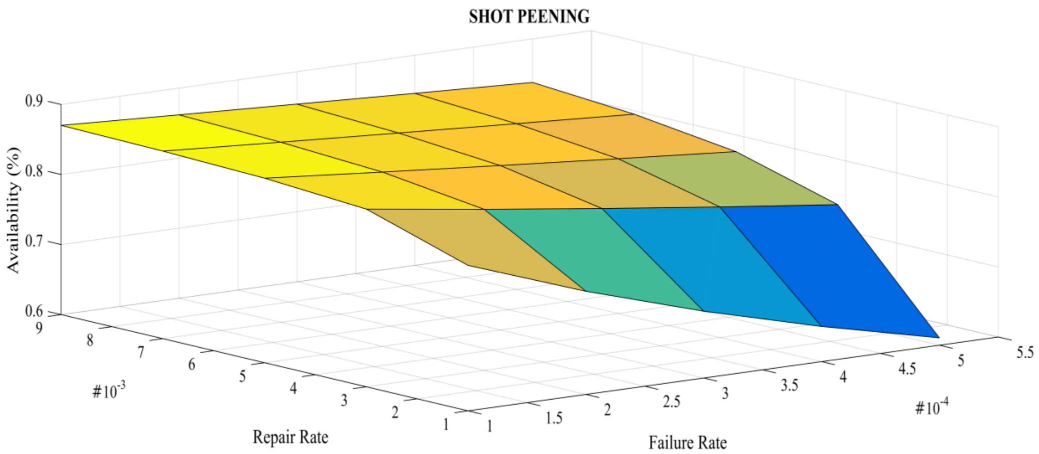

Fig. 2: *Effect of varying failure and repair rates of shot peening subsystem on system performability*

Table 3 and fig. 3 describe the effect of various failure and repair rates of painting machine on the performability of the system in terms of availability while other parameters remain constant. It is observed that when the failure rate increases from 0.0010 to 0.0090, the performability of the system decreases sharply from 0.8388 and 0.5755 (approx. 27%) and similarly when the repair rate increase from 0.0110 to 0.0910, the performability of the system increases from 0.8388 to 0.8990 (approx. 6%).

Table 3: *Effect of the failure and repair rates of painting machine subsystem on system performability (%)*

Failure Rates	Repair Rates of Painting Machine					Constant Parameters
	0.0110	0.0310	0.0510	0.0710	0.0910	
0.0010	0.8388	0.8822	0.8921	0.8965	0.8990	λ_1=0.0003
0.0030	0.7278	0.8347	0.8620	0.8745	0.8816	μ_1=0.0050
0.0050	0.6427	0.7920	0.8338	0.8534	0.8649	λ_3=0.0002
0.0070	0.5755	0.7535	0.8074	0.8334	0.8487	μ_3=0.0076
0.0090	0.5210	0.7186	0.7826	0.8143	0.8332	λ_4=0.0030
						μ_4=0.2000

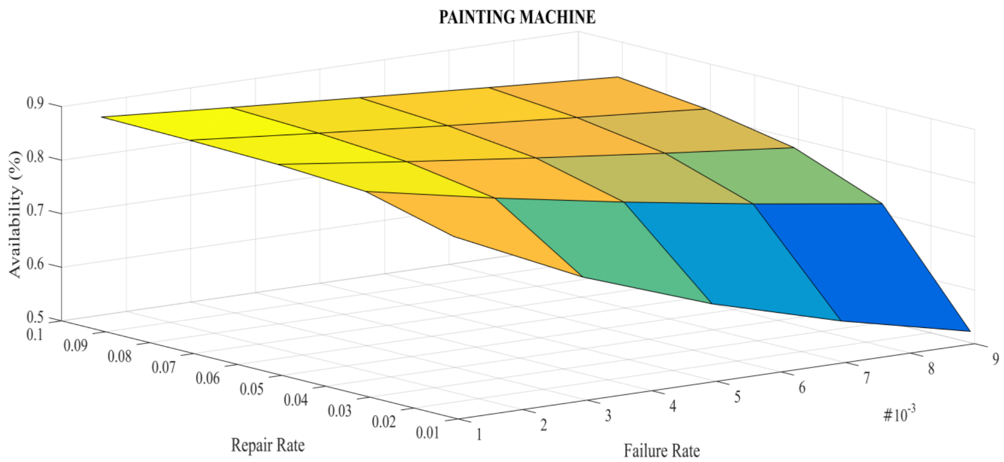

Fig.3: *Effect of varying failure and repair rates of painting machine subsystem on system performability*

Similarly, for the assembly platform the performability of the system in terms of availability varies between 67.37% to 84.59% (approx. 17%) for different combination of failure and repair rates of respective subsystem when other parameters remain constant as shown in the table 4 and fig.4.

Table 4: *Effect of the failure and repair rates of assembly platform subsystem on system performability (%)*

Failure Rates	Repair Rates of Assembly Platform					Constant Parameters
	0.0016	0.0036	0.0056	0.0076	0.0096	
0.0001	0.8102	0.8336	0.8406	0.8439	0.8459	λ_1=0.0003
0.0002	0.7711	0.8148	0.8282	0.8347	0.8385	μ_1=0.0050
0.0003	0.7357	0.7967	0.8161	0.8256	0.8312	λ_2=0.0030
0.0004	0.7033	0.7795	0.8044	0.8167	0.8241	μ_2=0.0310
0.0005	0.6737	0.7630	0.7930	0.8080	0.8171	λ_4=0.0030
						μ_4=0.2000

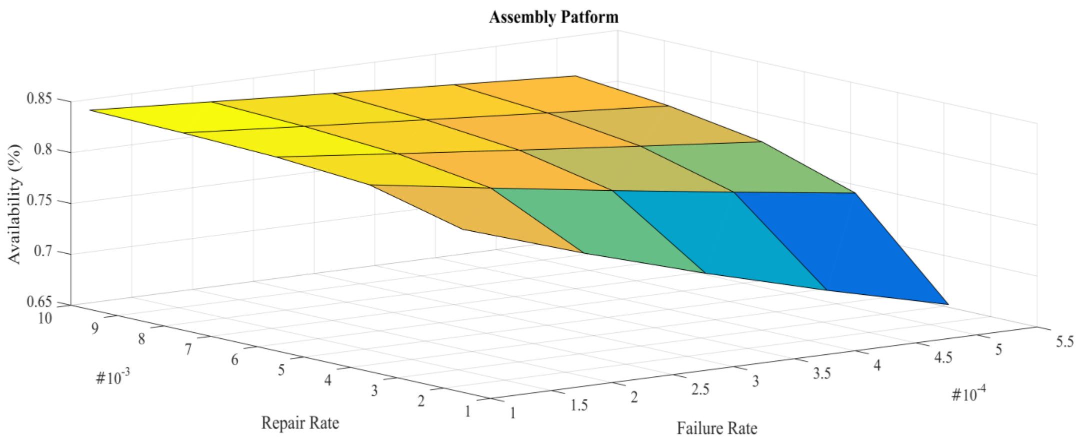

Fig. 4: *Effect of varying failure and repair rates of assembly platform subsystem on system performability*

Table 5 and fig. 5 reveal that variation in failure and repair rates of the riveting machine subsystem increases the system performability from 81.10% to 84.38% (approx. 3%) in terms of availability when other parameters remain constant.

Table 5: *Effect of the failure and repair rates of riveting machine subsystem on system performability (%)*

Failure Rates	Repair Rates of Riveting Machine					Constant Parameters
	0.1000	0.2000	0.3000	0.4000	0.5000	
0.0010	0.8382	0.8417	0.8429	0.8435	0.8438	λ_1=0.0003
0.0020	0.8312	0.8382	0.8405	0.8417	0.8424	μ_1=0.0050
0.0030	0.8243	0.8347	0.8382	0.8399	0.8410	λ_2=0.0030
0.0040	0.8176	0.8312	0.8358	0.8382	0.8396	μ_2=0.0310
0.0050	0.8110	0.8278	0.8335	0.8364	0.8382	λ_3=0.0002 μ_3=0.0076

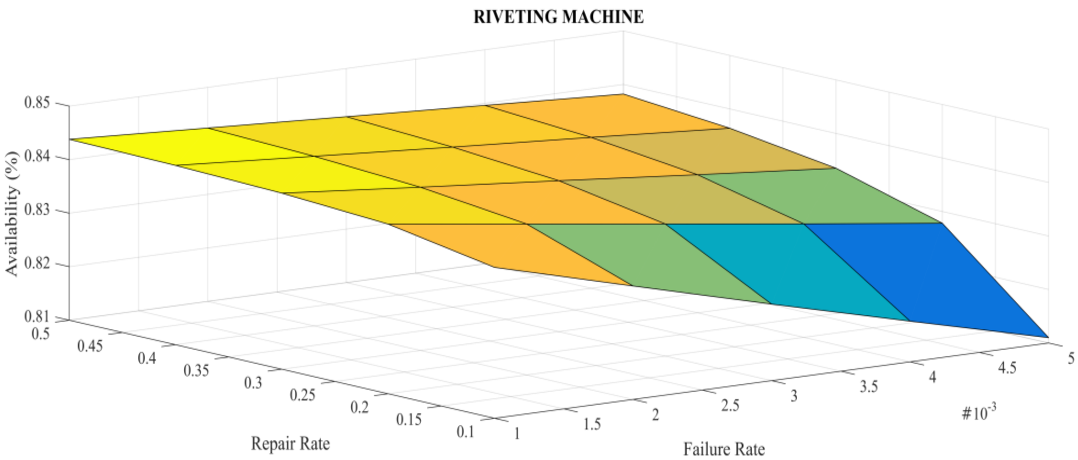

Fig. 5: *Effect of varying failure and repair rates of assembly platform subsystem on system performability*

These performability matrices (Table 2 to Table 5) are very helpful to propose the maintenance priorities for assembly line system. Painting machine has the highest impact on the performance of the system having a variation of 37.82% whereas the lowest impact is done by riveting machine where the variation of 3.28% occurs.

VI. Conclusions and Future Scope

The present work is a case study of assembly line system of leaf spring manufacturing plant. Performance analysis in term of availability is carried out using the Markova method. The study reveals that painting machine subsystem being the most critical component of assembly line system whereas riveting machine system being the lowest contributor in the performance of the system. On the basis of this detailed analysis, a DSS (Decision Support System) has been proposed for maintenance priorities for various subsystem of assembly line system due to which system performance will be enhanced. It is presented in the Table 6.

Table 6: *DSS for assembly line system*

Subsystem	Variation in Failure Rates λ (Repair Rates μ)	Effect on System Performability (%)	Recommended Maintenance Priority
Shot Peening	0.0001-0.0005(0.001-0.009)	0.8702-0.6105(25.97)	II
Painting Machine	0.0010-0.0090(0.011-0.091)	0.8990-0.5210(37.82)	I
Assembly Platform	0.0001-0.0005(0.0016-0.0096)	0.8459-0.6737(17.22)	III
Riveting Machine	0.001-0.005(0.10-0.30)	0.8438-0.8110(3.28)	IV

This work enhances the system performance using the Markovian approach. Markovian approach has some limitations; literature review reveals that use of Petri Nets overcomes these limitations. In fact, selection of appropriate technique had done an impact on maintenance costs. Further the results can be validated with some other robust techniques such as Genetic Algorithm (GA), Teacher Learning Based Optimization (TLBO), Ant Colony Algorithm (ACA), Particle Swarm Optimization (PSO) etc. for such industrial systems.

References

[1] Zhang, K. and Cao, H., "Reliability analysis of heat exchanging system of deep-sea manned submersibles using Markov model", Quality Engineering, 2021.

[2] Jiang, Q., Gao, D., Zhong, Li., Guo, S. and Xiao, A., "Quantitative sensitivity and reliability analysis of sensor networks for well kick detection based on dynamic Bayesian networks and Markov chain", Journal of Loss Prevention in the Process Industries, Volume 66, 2020.

[3] Salari, N. and Makis, V., "Application of Markov renewal theory and semi-Markov decision processes in maintenance modeling and optimization of multi-unit systems", Naval Research Logistics, 2020.

[4] Galagedarage, M. and Khan, F., "Dynamic process fault detection and diagnosis based on a combined approach of hidden Markov and Bayesian network model", Chemical Engineering Science, Volume 201, 2019, pp. 82-96.

[5] Malik, S. and Tewari, P.C., "Performance modeling and maintenance priorities decision for the Waterflow system of a coal-based thermal power plant", IJQRM, Volume 35, 2017, pp. 996-1010.

[6] Alizadeh, S. and Srinivas, S., "Reliability modeling of redundant safety systems without automatic diagnostics incorporating common cause failures and process demand", ISA Transactions, Volume 71, Part 2, 2017, pp. 599-614.

[7] Hassan, J., Thodi, P. and Khan, F., "Availability analysis of a LNG processing plant using the Markov process", Journal of Quality in Maintenance Engineering, Volume 22 , 2016, pp. 302-320.

[8] Shichang, Du., Rui, Xu., Delin, H. and Xufeng, Y., "Markov modeling and analysis of multi-stage manufacturing systems with remote quality information feedback", Computers & Industrial Engineering, Volume 88, 2015, pp. 13-25.

[9] Kumar, R., "Availability analysis of thermal power plant boiler air circulation system using Markov approach", Growing Science Ltd., 2013, doi: 10.5267/j.dsl.2013.08.001.

[10] Liu, Z., Liu, Y., Cai, B., Li, J. and Tian, X., "Markov Modeling of Double 2-out-of-2 System with Imperfect Detection and Common Cause Failures", International Conference on Computer, Networks and Communication Engineering, 2013.

[11] Kumar, R., Sharma, A. and Tewari, P. C., "Markov approach to evaluate the availability simulation model for power generation system in a thermal power plant", International Journal of Industrial Engineering Computations, Volume 3, 2012, pp.743–750.

[12] Vora, Y. and Tewari, P. C., "Simulation model for stochastic analysis and performance evaluation of steam generator system of a thermal power plant", International Journal of Engineering Science and Technology, Volume 3, 2011, pp. 5141-5149.

[13] Ge, H. and Asgarpoor, S., "Reliability Evaluation of Equipment and Substations with Fuzzy Markov Processes", IEEE Transactions on Power Systems, volume 25, 2010, pp. 1319-1328.