Markov Chains a Novel Approach for Availability Analysis of Industrial Systems

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Abstract

Markov chains are being relegated to the list to rarely used stochastic modeling techniques for availability modeling of complex systems. In modern period of mechanization there is requirement to use high end equipment to achieve the anticipated production targets. Therefore, the main job of plant manager/ engineer is to ensure availability to these equipment's in a plant for high profit ratio. Hence, availability assessment of a plant is essential in current scenario. There are many tools and techniques for availability assessment, but Markov chains is most widely used by researchers for stochastic modeling. This Paper presents the use of Markov chain for modeling of a complex system using reachability graphs.

Keywords: Reachability Graph, Markov Chain, Availability, Simulation.

1.Introduction

It is vital to save the system free from failures as much as possible within given operating conditions to achieve higher production goals and system availability. In the current age of automation of systems in the industry, achieving the greater value of plant availability is a stimulating task for the plant managers. Numerous research work had been published over the years to assess the system availability using mostly analytical techniques and very few with simulation approach. [1] studied the availability modeling of a shoe upper manufacturing plant using Markov approach. They used the Runge-Kutta technique to explain the probability differential equations for finding various performance parameters of a plant. [2] followed the Markov Birth-Death probabilistic approach for the formulation of a mathematical model to find the availability of a thermal power plant. [3] presented the lambda-tau based mathematical modelling technique for finding the availability analysis of a fertilizer plant. [4] discussed the RAM analysis of continuous casting plant using semi Markov approach.[5] used Markov approach for the performance analysis of the combed yarn plant. They have applied the Lagrange method to obtain the several state probabilities.[6] computed availability, reliability and Mean Time to Failure (MTTF) for a plastic-pipe industrial plant containing of K/N units using matrix calculus method assuming the constant failure rate for different components of the system. [7] presented the availability analysis using generic Markov models. [8] studied the availability model of a washing system using a Markov model in a paper industry. [9] carried out the availability analysis of chemical plants using Markov chains.[10] used markov chains to analyze the system availability of a boiler in thermal power plant.[11] did the comparison of the markov chains with the RBD and discussed the supremacy of the former method.

2. Markov Chains

The Russian mathematician A.A. Markov introduced a special type of stochastic process in year 1907, whose present state uniquely determines the future probability i.e., with conduct of non-hereditary or memory-less. The performance of a many of physical systems falls into this category, therefore it can be used for availability and reliability modelling of these systems. A markov chain is stochastic process which includes the discrete time and state space which are discontinuous. Whereas the continuous time space represents the Markovian process. The state transition diagram of the above illustrated example is depicted in the figure 2 with some assumptions listed below. The following assumptions are taken into consideration while using state space diagram.

Assumptions:

A^W,B^W,C^W,D^W : It indicates the working state of the components.

A^F,B^F,C^F,D^F : It indicates the Failed state of the components.

λ_i: Represents the mean failure rate of the Components.

μ_i: Represents the mean repair rate of the Components.

Pi(t): Probability at time "t" that all components are good and the system is in i^{th} state.

To illustrate the use of Markov, approach an example of series parallel arrangement of four components is considered as shown in the figure 1.

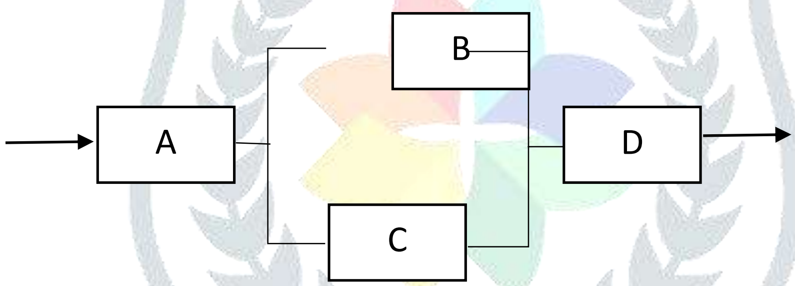

Figure 1. Series-Parallel system

Consider a system comprising of four components A, B, C and D arranged in series and parallel arrangement. The constant repair and failure rates of the four components are $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ and $\mu_1, \mu_2, \mu_3, \mu_4$ respectively. Failure of all the four components brings the system in down state, whereas if A component fails only then system will also come to down state. Failure of three components B, C and D will also lead to the system failure, whereas system will run in reduced state if either A and B are in working condition or A, D and C are in working conditions.

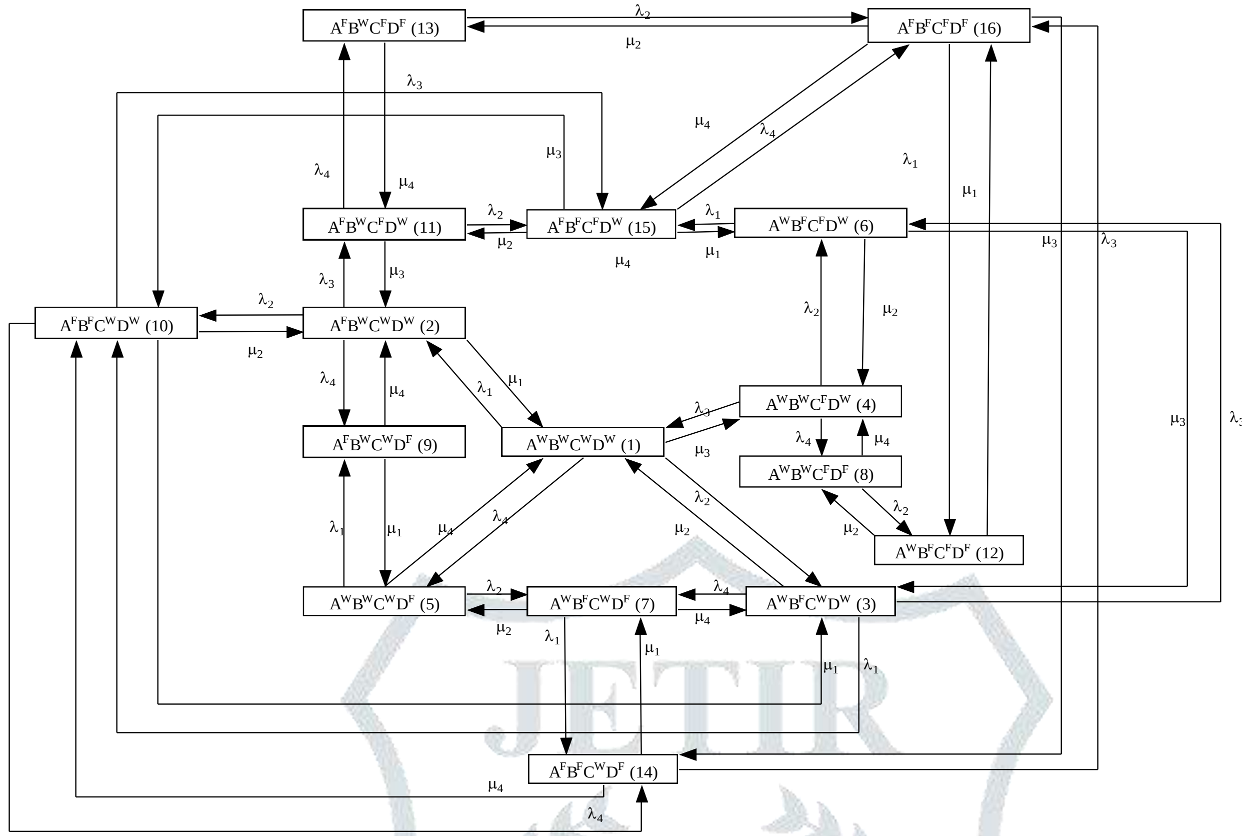

Figure 2. State transition diagram

With respect to the state transition diagram some of the first order differential equations for probability considerations are as under.

$$\frac{dP_1(t)}{dt} + (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)P_1(t) = \mu_1 P_2(t) + \mu_2 P_3(t) + \mu_3 P_4(t) + \mu_4 P_5(t) \quad (1)$$

$$\frac{dP_2(t)}{dt} + (\lambda_2 + \lambda_3 + \lambda_4)P_2(t) = \mu_2 P_{10}(t) + \mu_3 P_{11}(t) + \mu_4 P_9(t) \quad (2)$$

$$\frac{dP_3(t)}{dt} + (\lambda_1 + \lambda_3 + \lambda_4)P_3(t) = \mu_1 P_{10}(t) + \mu_3 P_6(t) + \mu_4 P_7(t) \quad (3)$$

$$\frac{dP_4(t)}{dt} + (\lambda_2 + \lambda_3 + \lambda_4)P_4(t) = \mu_2 P_6(t) + \mu_3 P_1(t) + \mu_4 P_8(t) \quad (4)$$

$$\frac{dP_5(t)}{dt} + (\lambda_1 + \lambda_2 + \lambda_3)P_5(t) = \mu_1 P_9(t) + \mu_2 P_7(t) + \mu_4 P_1(t) \quad (5)$$

$$A(t) = P_1(t) + P_2(t) + P_3(t) + P_4(t) + P_5(t) \quad (6)$$

Similarly, another differential equation can be written for probability consideration for all other states of the diagram. These differential equations can be solved with the Laplace transformation using various numerical methods. The availability of this system can be found from eq. (6).

3. Reachability Graph

The foremost problem confronted by the plant engineer while doing the availability analysis of a complex system to transmute the problem into Markov chain. This problem is being easily dealt with the help of reachability graph. The state evolutions of state transition diagram are characterized by the markings of reachability graph. As revealed in figures 2 and 3 the change in the state of the state of the system as soon as the transition fires. As shown in the figure marking M_0 is changes to M_1 by firing transition T_1. For a complex system, it's easy to develop the reachability graph from the model of the system and further transform it into Markov chain.

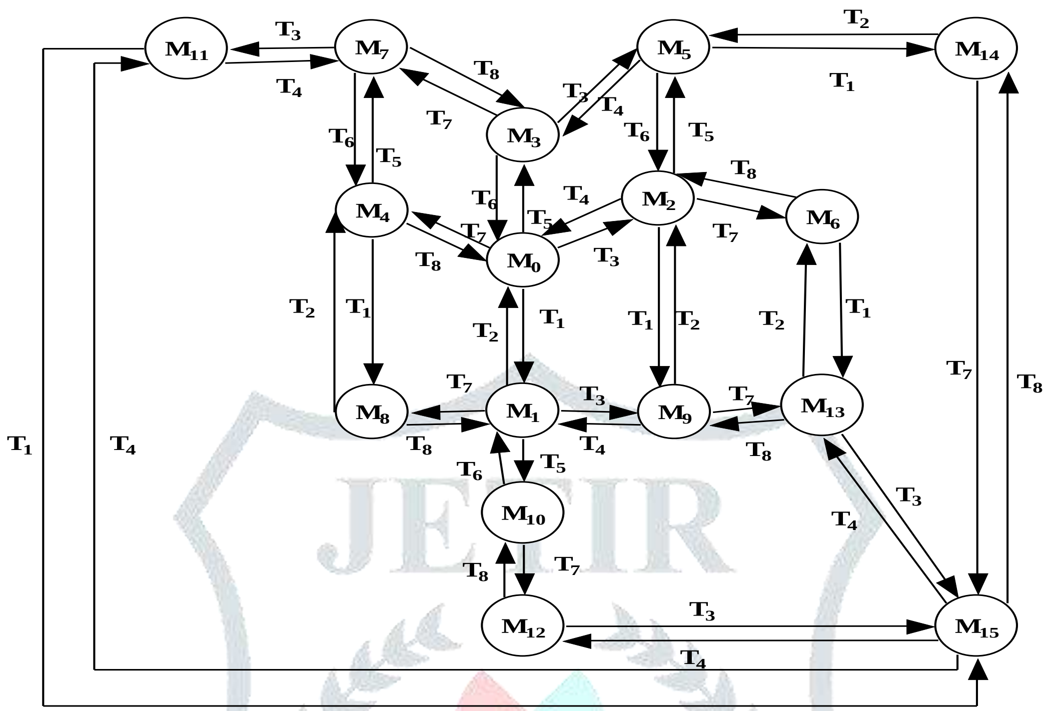

Figure 3. Reachability Graph

4. Conclusion

There are numerous analytical and simulation-based methods are being used to study the performance parameters of the system. The Markov chains is one of the most extensively used analytical method to study the plant performance parameters. An attempt has been made in this paper to use the Markov chains for availability assessment of complex systems. It was observed that the state space method (Markov process) is appropriate for complex systems. The straightaway formulation of the markov chains is difficult and requires time for large complex systems. Therefore, for the complex systems under study, the reachability graph is first formed and then transformed into the Markov chains. The equations formation from the state transition diagrams is very simple and is used for calculation availability assessment of a complex systems.

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