Modelling of repairable systems using Petri Nets

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Abstract

This paper presents the modeling of the repairable systems using Petri net. Petri net has appeared as a promising graphical tool for system modeling the stochastically repairable systems. It gives the dynamic behaviour of the respirable systems which helps the plant managers to study the behaviour various subsystems of a given system and plan their maintenance accordingly.

1.Introduction

In today's era the use of automation and high-end technology to aim the high production goals imposes a challenge to plant managers for maintaining high availability of systems. The failure of systems is unavoidable Therefore it is essential for plant managers to study the dynamic behavior of repairable systems to achieve high availability and reduce the failure rate of systems. Though there are various modeling tools like reliability block diagram, fault tree analysis, event tree analysis, decision tree analysis, and Markov chains to predict system performance parameters (reliability, availability, etc.), as far as the performance analyzes of repairable systems are concerned, the Markov chains are the most commonly used. However, the major difficulty met by the reliability engineers is to directly translate their statement into a Markov chain. Another problem encountered is of incorporating the interdependency of the units/components of a system into the Markov chain. A reachability graph for Petri net model provides a solution to these problems**.** Petri Nets have emerged as a powerful modeling tool which contains places, transitions and arcs which represented by circles, rectangles and arrow heads respectively. The places represent the events and transitions represents conditions to fire the events. A simple example of four unit system is considered below for petri net modeling.

Consider a four-unit system (A, B, C, and D) for which configuration is shown in Figure 1.

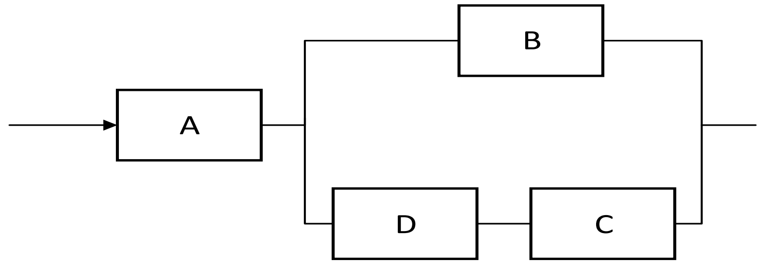

Figure 1. Four component repairable system

The system is in working state when unit A works and either of unit B or unit C and D works. The system fails when either unit A fails, or all the units B, C and D fails. The Petri net model is illustrated in Figure 2. In the Petri net model, the tokens associated with ($P_{A\_Working}$, $P_{B\_Working,}$ $P_{C\_Working}$, $P_{D\_Working}$) shows that the unit A, B, C, and D are working. ($P_{A\_under\ repair}$,$P_{B\_under\ repair}$, $P_{C\_under\ repair}P_{D\_under\ repair}$) represents that the failed units are under repair.$P_{\_System\_Up}$ is marked with a token indicating the whole system is in working state and no failure has occurred yet. $P_{\_System\_down}$ indicates that the system is in downstate due to some faulty unit the firing of transitions associated with the failure event (i.e.T_1, T_3, $T_{5,}$ and T_7) eliminates the token from the upstate condition of that unit and enhances a token to the places meant for repair ($P_{A\_under\ repair}$, $P_{B\_under\ repair}$, $P_{C\_under\ repair}P_{D\_under\ repair}$) of the respective units. The timed transitions T_1, T_3, $T_{5,}$ andT_7 are related with the respective times to failure of the associated units. (t_1, t_2, t_3, t_4) are the immediate transitions. The transition T_1 will fire as soon as delay time has elapsed, the token from place $P_{A\_Working}$ moves to$P_{A_Wait_Repair,}$ thus enabling the guard condition at immediate transition t_5. This movement results in the removal of another token from place $P_{\_System\_Up}$ to Place $P_{_System_down}$and brings the system from upstate to downstate. The transition t_1 is enabled with the failure of unit A (as both the places $P_{A\_Wait\_repair}$ and $P_{repairman}$contain token) and it fires immediately. The token is removed from places $P_{A\_Wait\_repair}$ and $P_{repairman}$ and is moved to place $P_{A\_under\ repair}$. The transitionT_2 gets enabled and after associated delay puts a back system in the upstate. The availability of the system is computed by the probability of the token in the $P_{\_System\_Up}$.

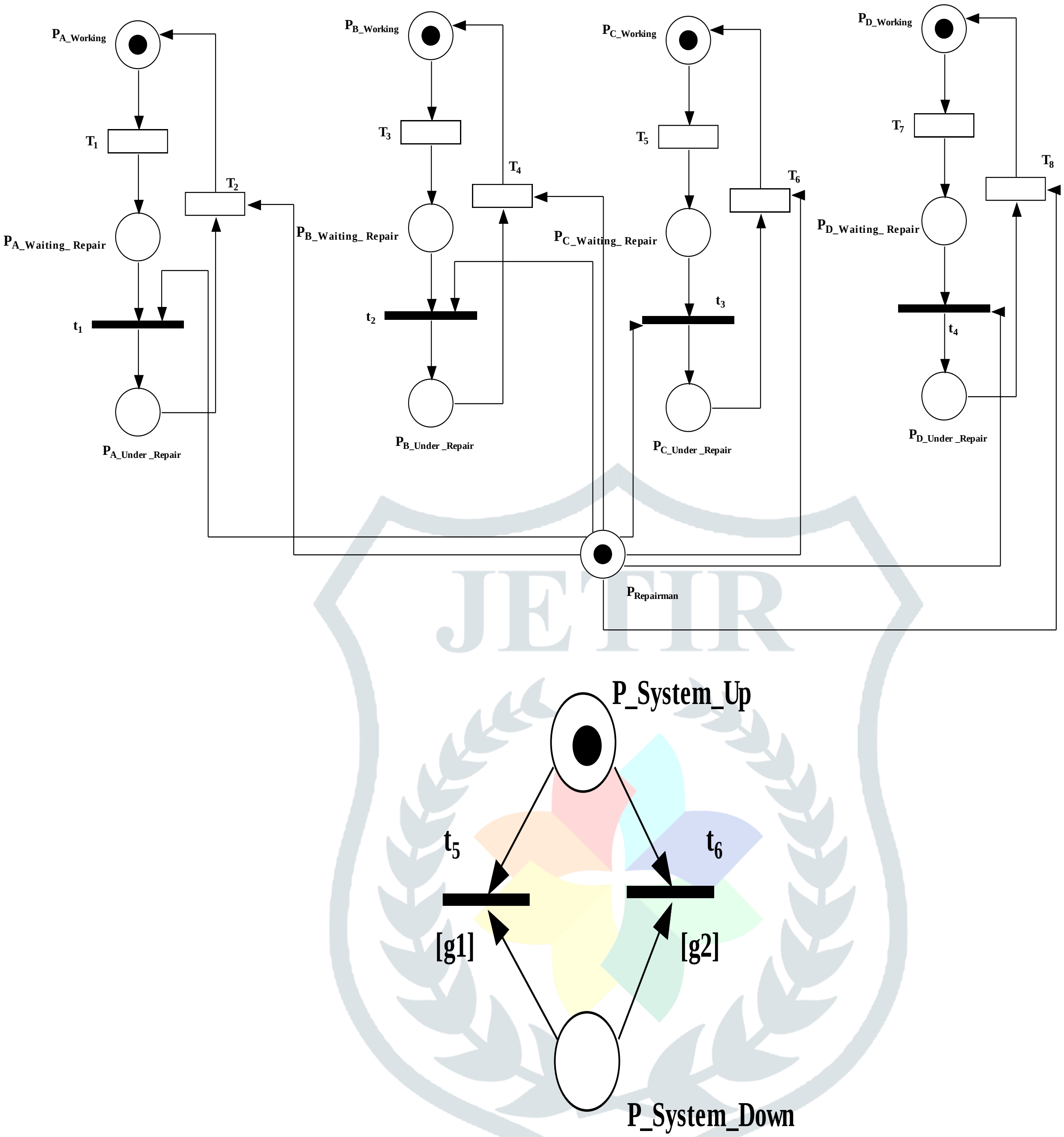

Figure 2. Petri Net Model of a repairable system

2. Reachability Graph of a repairable system

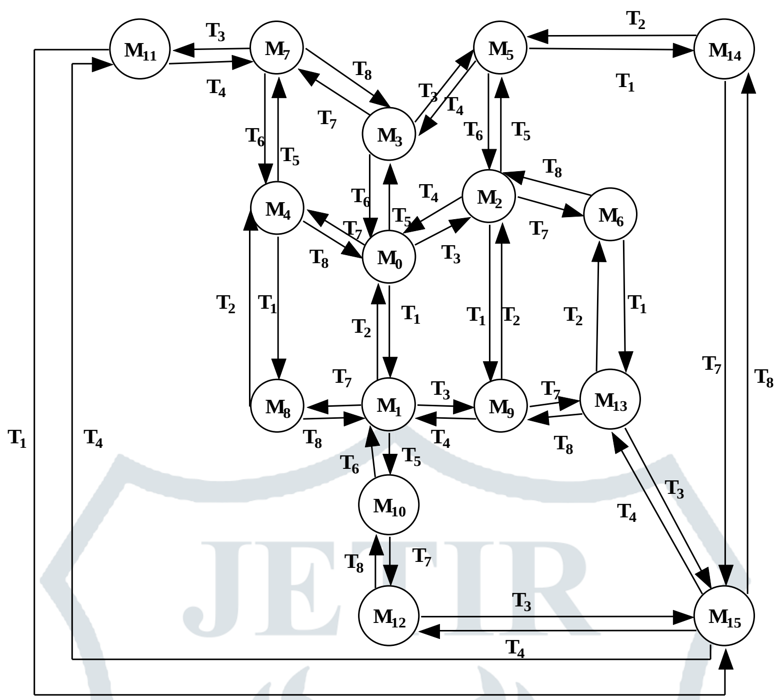

Figure 3. Reachability Graph

There is a total of sixteen markings in a graph where M_0 represents the initial marking, which signifies the system is in working condition. The directed arcs indicate a change in different markings or the state evolution as soon as transition triggers, for instance marking M_0 can be reached to marking M_1 with the firing of transition T_1 as shown in Figure 3. These markings can be easily obtained by modeling a system by Petri nets. The reachability graph is equivalent to a Continuous Time Markov Chain)CTMC) where the markings represent the states and the transitions correspond to the rates. Then, the state transition rate matrix is prepared, and the performance parameters are estimated by analyzing the Markov chain. The transient and steady-state analysis of the system is done by solving formulated differential and linear equations, respectively, with analytical/numerical methods. The Markov state space diagram of the above reachability graph is shown in Figure 4.

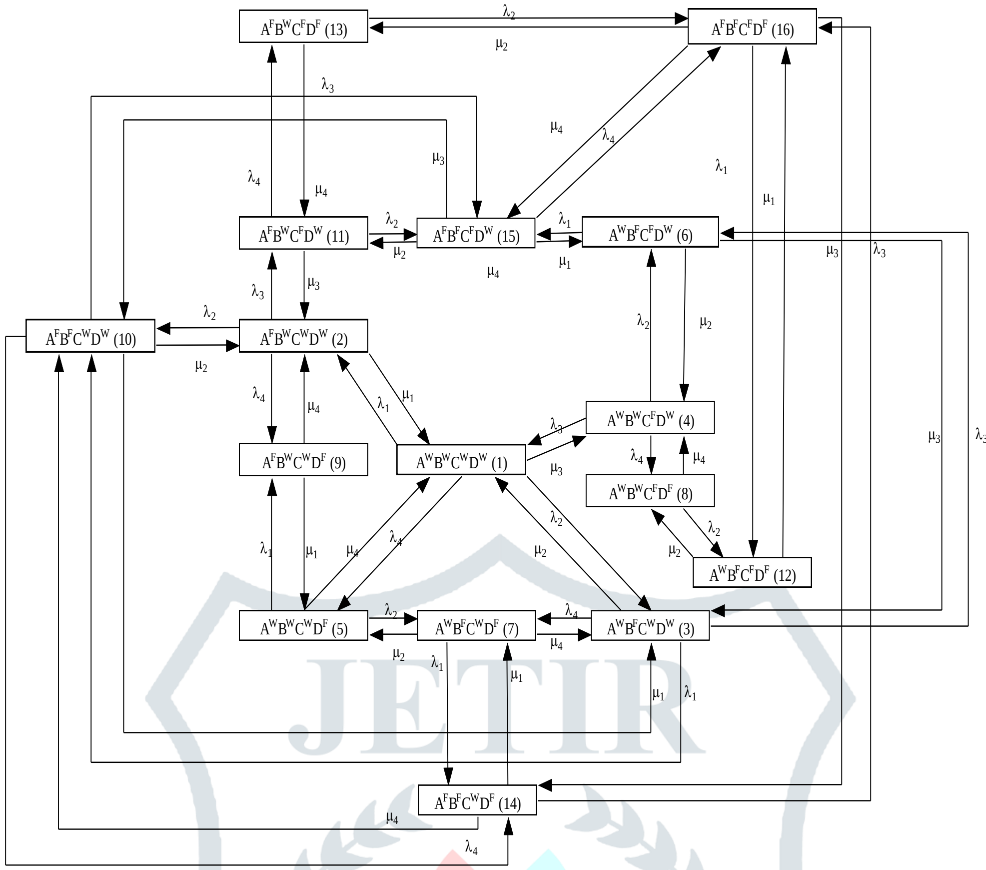

Figure 4. State Transition Diagram

Where

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

A^F, B^F, C^F, D^F : It represents the failed state of the units.

λ_i: Represents the mean failure rate of the units.

μ_i: Represents the mean repair rate of the units.

Pi (t(: Probability that at time "t", all components are good, and the system is in the i^{th} state. Although the state transition diagrams are easy to formulate for small systems as the number of components of the system increases, the system more complex and the size of the state transitions grows exponentially. These limitations are circumvented with Petri nets as they are easily formulated even for complex systems and one can produce the reachability graph of the Petri net model.

4. Conclusion

Petri Net modeling has been one of the dynamic graphical tools to study the behavior of the repairable systems. It is an interactive tool for examining the behavior of various components of a system under different conditions of failure and repair distribution patterns. Many other tools such as reliability block diagram, fault tree analysis, Markov chains, event tree analysis is available for modeling but they do not consider the dynamic nature of the system. Also, these tools are not user friendly and easy to develop the model of the system. This paper gives an insight into the use of the Petri net for modeling the repairable systems.

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