ISSN: 0971-1260

Vol-22-Issue-17-September-2019

Petri Net based approach for modeling and availability analysis of Corrugated Box Manufacturing Plant

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Abstract

Availability analysis of the repairable engineering system is helpful in minimizing the failures thereby attempts to achieve the required production targets. As high productivity and high production goals become the necessary part of an organization to survive. To affect this, the paper attempts to present the Petri net-based approach to develop the model of various subsystems of a corrugated box plant for availability analysis . The modeling of a system describes the dynamic behavior of the system which is helpful for plant engineers to understand the interaction among the various subsystems under varying operating conditions. The performance parameters such as system availability, percentage of time system is in a reduced state and repairmen utilization gives more insight to the plant engineers under varying operating conditions and helps them in deciding the suitable maintenance actions to increase the system availability and consequently reduce the cost.

Keywords: Petri nets, Availability, Performance analysis, Modeling, Simulation

1. Introduction

In current industrial scenario the increasing demand for automation of the industrial systems lead to the high capital expenditure of installation. Therefore the high levels of production and profits are desired. To achieve this end, the availability of the engineering systems must be maintained to highest value.
Unfortunately, failure can’t be avoided even though it can be reduced by adopting proper maintenance policies. Therefore, to achieve higher production targets the plant managers must crtically analyse the system performance. For engineering systems to survive, the gusty productivity ratios and availability of systems are desired. The analysis of the various availability parameters of the systems helps the plant managers to understand the dynamic nature of the system.

In the last few decades, the literature reflects the various techniques for reliability and availability modeling in the different areas of the applications. Many tools such as fault tree diagram, reliability block diagram, FMEA, Markov chains, have been discussed by various authors to analyze the engineering systems behaviour. A literature survey on the various techniques used for modeling of engineering sytems is as discussed below.

2. Literature Review

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[19] carried out the availability analysis using the fault tree technique for chemical refinery. [15] discussed the use of reliability block diagrams in the petroleum refineries to identify potential effects of single failures. Although the application of RBD and fault tress techniques in performance modeling have been discussed by several authors but these techniques do not addressees the dynamics of the system. Several authors discussed the application of Markov chains to carry out performance modeling of the engineering systems. [4] pointed out the behavior analysis for a engineering system of the thermal plant using Markov approach. [8-9] discussed the reliability modeling for a oil and pipe manufacturing plants using Markov approach. They discussed the results of variation of repair and failure times on the reliability and availability of the system. [19] discussed the Markov model of a casting plant for evaluating various performance parameters. [3] discussed the reliability modeling of a pod propulsion system. [23] carried out the RAM analysis using lambda-tau approach for fertilizer plant. [16] discussed the Markov model of a shoe plant and studied the various performance parameters. [2] presented the availability analysis of a gas sweetening plant using a Markov approach.

Although the use of the Markov approach is extensively used in literature by several researchers for modeling the repairable systems, as the system becomes more complex, this approach complicates the formation of a state-space diagram and it is hard to formulate the Markov chain. Furthermore, it is difficult to solve the long analytical equation for finding the solution. These limitations are succesfully tackled with the Petri nets (PN) which emerges as a powerful simulation and modeling tool. Petri nets have various applications as discussed in the literature by various researchers. [17] discussed the various basic properties of the Petri nets. [18,10] discussed the applications of petrinets in the filed of operation research.[24] studied the use of Petri nets in performance analysis of complex systems along with aging tokens. [14,2] discussed the Petri nets based approach for reliability modeling of a production plant. [26] presented the modeling of flexible manufacturing systems using Petri nets. [21-22] discussed the Petri net modeling of the various subsystems of feeding and pulping equipments of a paper plant.

[13] pointed out Petri nets use in the filed occupation health safety. [25] discussed the petri net based approach to calculate various reliability parameters for a wind turbine. [12] discussed the applications of Petri net in the filed of the railway networks. [6] carried out the performance analysis of the fuel cell systems using Petri nets. [5] presented the performance analysis of a distillery plant using Petri nets. The Petri nets have emerged as a powerful modeling tool to study the dynamic behavior of the systems. This paper presents the great modeling power of the Petri nets has been explored to carry out the availability modeling of a corrugated box manufacturing plant. An outline of Petri nets has been discussed in the next section.

3. Petri Nets Description

Petri nets are represented by a bipartite graph that has between places, transitions and directed arcs. The transitions (drawn by rectangular bars) which represent the event and places P (represented by circles) which represent condition for the corresponding events. An arc is used to connect the place with transition. The input arcs (Places to transitions) and output arcs (transition to places). Each arc is associated with a weight that represents the multiplicity of an arc. By default, every arc has a unit multiplicity. The places carry the tokens in form of dots.The transitions also have inhibitor arcs. Graphically a small dot at the end of the arc is used to represent the inhibitor arc. It is used to confine the movement of the token between

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place and transition when the multiplicity of input arc is equal to a number of tokens in the place.
A transition gets enabled if the all the input places to the transition carries a token corresponding the weight of the input arc. The guards are associated with the transitions to control the firing of a transition after the required conditions are fulfilled.
The original definition of Petri nets does not include time delays. It is essential to relate the time delays with the transitions to study the dynamic systems. Therefore, the extension of Petri nets was introduced as stochastic petrinets which considers the various distribution-based time delays associated with transitions. Also, the concept of immediate transitions has been described with generalized stochastic Petri nets.

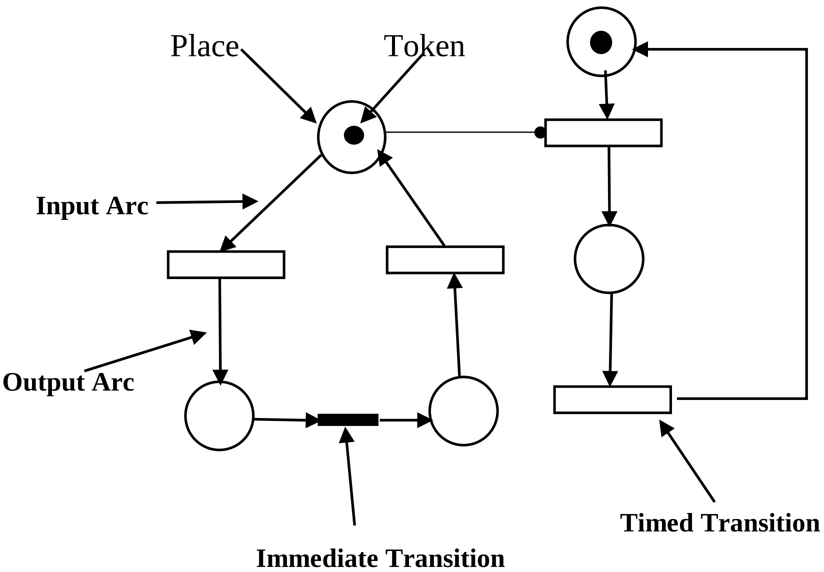

Figure 1. Petri Net

4. System Description

The system has four machines, namely corrugation machine (two off), pasting machine (two off), slotting machine (two off) and Stitching machine (two off) as shown in Figure 2. Firstly, the raw material in form of Kraft paper sheets is sent to the corrugation machines where the layers of these are heated, glued using corn starch glue and then pressed together to form a corrugated board sheet. Further, these sheets are cut by broad cutters and pasting is done on the pasting machine. After that, they sent for slotting operation on the slotting machines where the required size of the cardboard sheets is slotted and finally these are stitched to get the required final product. The maintenance data related to the various machines has been obtained after consultation with the plant engineering and maintence log books.The maintenance related data of machines is shown in Table 1.

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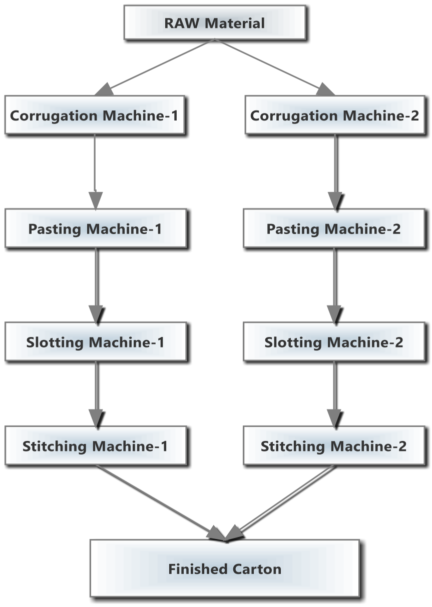

Figure 2. Process Flow of corrugated box manufacturing plant

M/Cs in Box Plant	Failure Time (Weibull Type Distribution)			Repair Time (Exponential Type
	Scale Parameter (α)	Shape Parameter (β)	MTBF (Hrs.)	MTTR (Hrs.)
Corrugation M/C	50.5	1.84	51	3.5
Pasting M/C	87.2	2.84	75.8	2.0
Slotting M/C	101	2.47	91.5	2.5
Stitching M/C	131.4	2.96	119	1.0

Table 1. Maintenance data of the various M/Cs of the corrugated box plant

Assumption considered for the model

1. The repair of the system depends upon the availability of the repair team.
2. Repair and Failure times are independent of each other.
3. A priority of repair is assumed.
4. After repair the system is restored to its original condition.
5. Random failures can occur simultaneously in the system.

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5. Petri net model

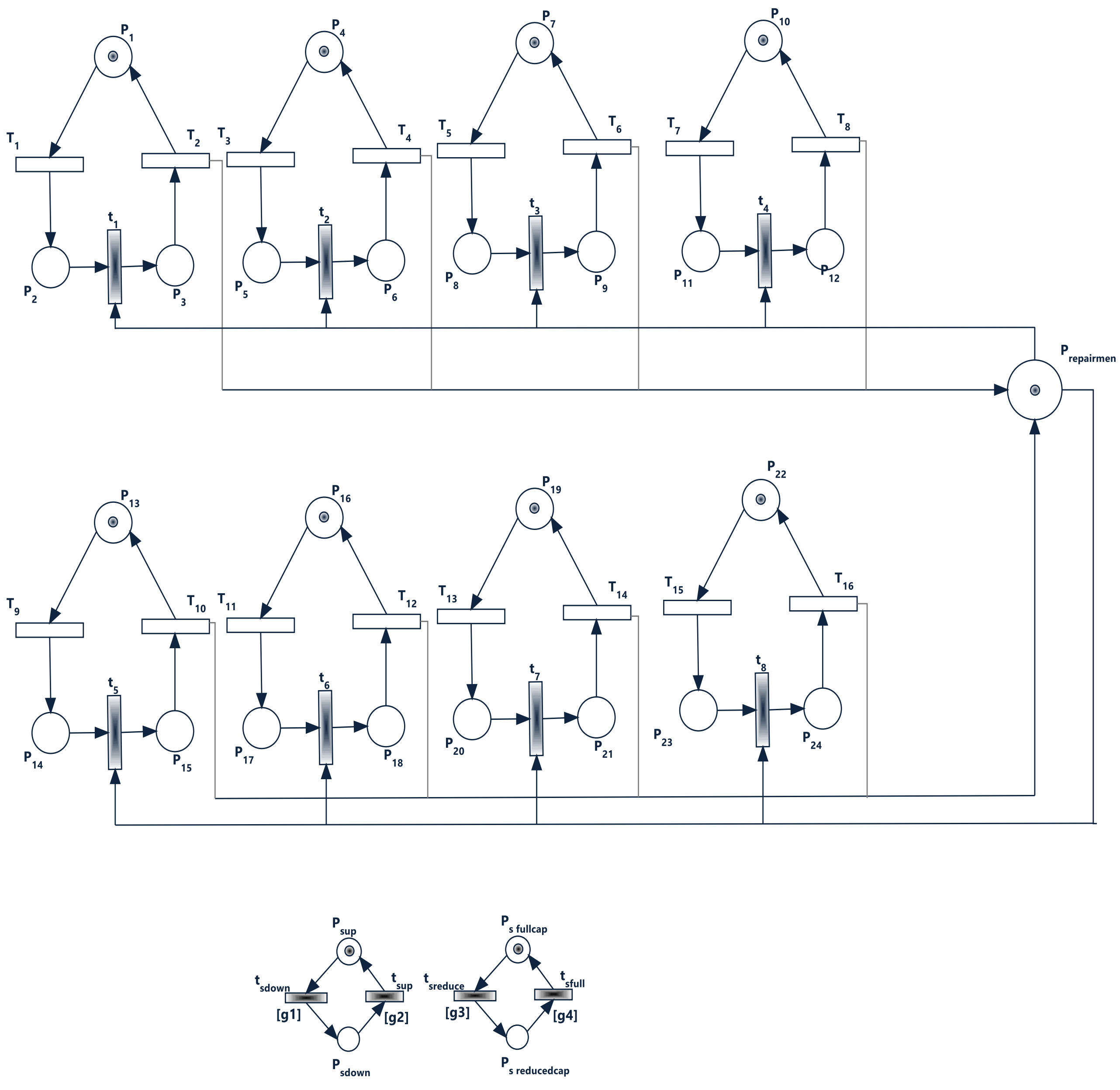

Figure 3. Petri Net Model of a Corrugated Box Manufacturing Plant

Figure 3 shows the petri net model of the corrugated box manufacturing plant.. The model depicts various places and transtions as shown in Table 2.

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Places and Transitions	Description
Places(P_1, P_4, P_7, P_{10}......)	respresnts the working state of the system
Places(P_2, P_5, P_8, P_{11}..........)	represents the machines have to wait for repair
Places (P_3, P_6, P_9, P_{12}....)	represents the state of the system under repair
Place (P_system_up state)	represents working state of the system
Place (P_system _down state)	represents down state of the system
Transitions (T_1, T_3, T_5, T_7….)	represents the timed transitions for the stochastic delay for failure
Transitions (T_2, T_4, T_6, T_8…)	represents the timed transitions for the stochastic delay for repair
Transitions (t_1, t_2, t_3, t_4……)	represents the immediate transitions

Table 2. Description of Places and Transitions of Petri net model

5.1 Dynamic Behavior of model

The places (P_1, P_4, P_7, P_{10}.......) carrying token represents the four machines are initialy working. The transitions (T_1, T_3, T_5, T_7.......) are initially enabled due to the presence of tokens at the input places. With failure of any of the machine depending upon the time delay for corresponding transition the firing of respective transitions fires which causes the movement of tokens to the next places (P_2, P_5, P_8, P_{11}.......) resulting in the downstate of the line. As soon as these places gets the token the immediate transitions (t_1, t_2, t_3, t_4......) gets enabled subject to satisfaying the guard conditions (Reapirman availability) . The fring of immediate transition leads to movement of the token to next places (P_3, P_6, P_9, P_{12}....) respectively. As the transitions (T_2, T_4, T_6, T_8.......) gets enabled they move the tokens to the places after the respective time delays. In the given model the repair crew of five is being considered.

6.**Performace Parameter Analysis**

The Petri net module of (TOTAL GRIF software) is used in the present study to carry out to analyse the sytem on verious performance parameters. The simulation asses various performance parameters of the system (availability, percentage of time the system is in reduced state and effect of repairmen on the system availability). The model is simulated for 4,000 replications for a time period of two years at a 95 % confidence level. The effect of variation of repair and failure times of all the machines on the system availability and percentage of time the system is working at reduced capacity is shown in Table 3. It can observe from the Figures (4-7) with an increase in the failure times and decrease in the repair rate of the machines the system availability increases. However, as seen from the Figures (4-7), the corrugation machine has more impact on system availability as compared to another machines. This

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observation will aid the plant engineers to plan for appropriate maintenance policy for these machines. The effect of an increase in the repairmen on the plant availability is dipicted in Figure 8. The improvement in system availability is achieved by increasing the repairmen. The maximum value of system availability is achieved with the crew of three repairmen which signifies that the three repairmen are sufficient in the plant for carrying out maintenance work.

Machines	Failure Times (Variation in Hrs.)	Repair Times (Variation in Hrs.)	System Availability	Percentage of time the system is running at reduced capacity
Corrugation M/C	35-66	(2.5-4)	0.91-0.95 (0.96-0.90)	13.83–12.40 (10.40–13.53)
Pasting M/C	65-100	(1- 3)	0.90-0.96 (0.95-0.91)	11.30-9.90 (10.50-11.6)
Slotting M/C	60-110	(1.5-2.5)	0.93-0.97 (0.97-0.94)	11.22-9.12 (10.2-12.3)
Stitching M/C	90-150	(0.5-2)	0.95-0.98 (0.94-0.92)	10.5-8.7 (10.2-11.4)

Table 3. Effect of variation of repair and fialure times of machines on the system availability

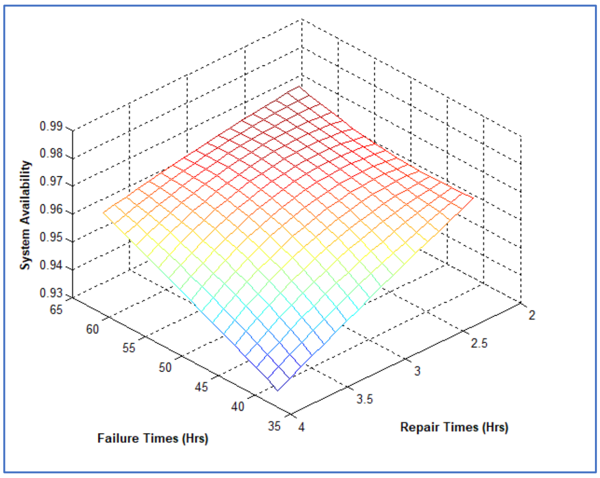

Figure 4. Effect of Failure (Repair) times of the Corrugation Machine on system availability

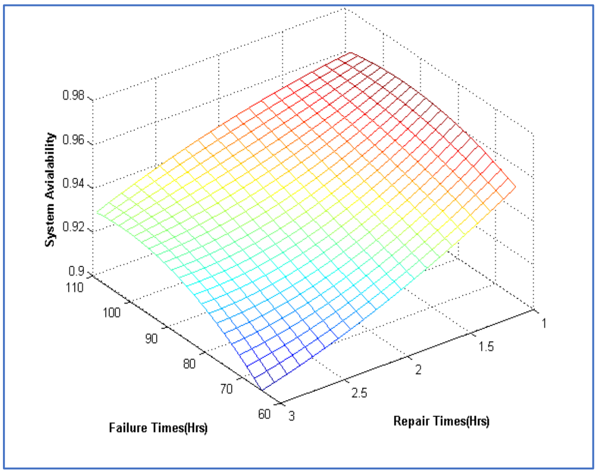

Figure 5. Effect of Failure (Repair) times of the Pasting Machine on system availability

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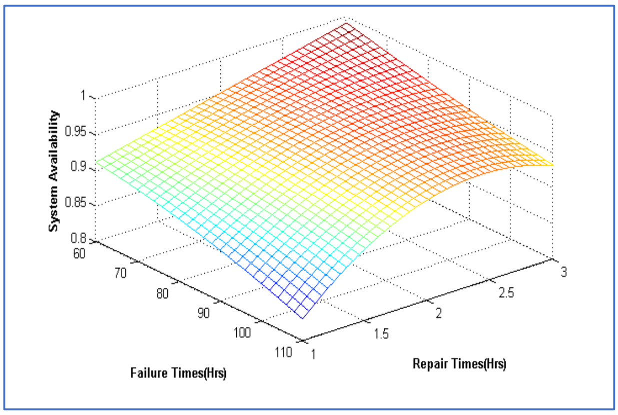

Figure 6. Effect of Failure (Repair) times of the Slotting Machine on system availability

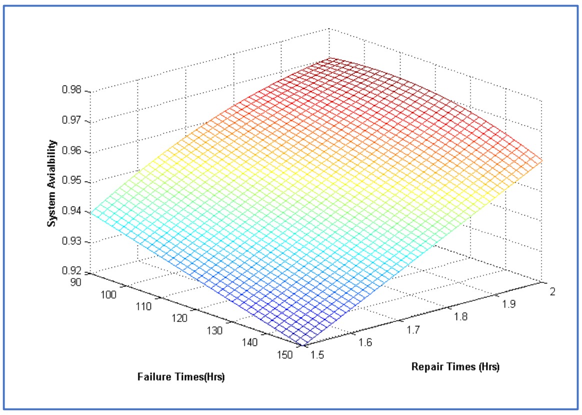

Figure 7. Effect of Failure (Repair) times of the Stitching Machine on system availability

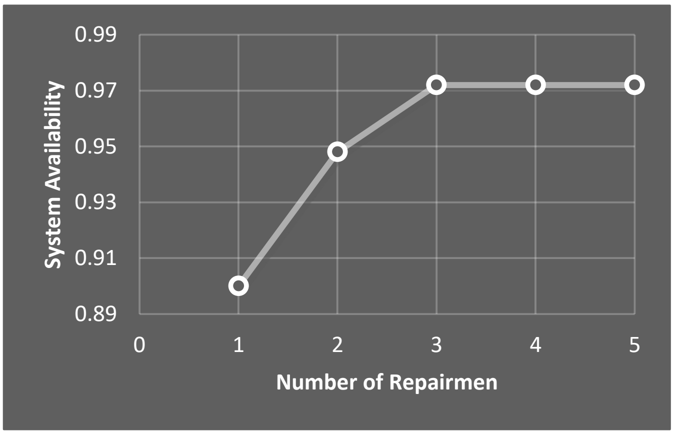

Figure 8. Effect of number of repairmen on the system availability.

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7. Conclusion

This paper presents Petri net-based methodology to examine the dynamic behavior of the system and to analyze the various performance parameters of the manufacturing plant. The Petri nets has emerged as a powerful modeling tool to examine the sensitivity analysis of the system. Based upon Petri net modeling of a system the plant engineers easily identify the interactions among the various subsystems and the use of guards make the system more interactive and closer to the real world. The performance analysis of the corrugated box manufacturing plant depicts the outcomes of variations of failure and repair time on the system availability and also the percentage of time the system is working with reduced capacity. These parameters help the managers to decide upon the maintenance policies to improve upon the availability of the plant. Further, it is observed an increase in the repair crew does affect the plant availability which helps in allocation maintenance manpower planning.

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