

Chapter 20

Analyzing the Effect of Different Maintenance Policies on the Performance of Flexible Manufacturing Cell



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Abstract Flexible manufacturing cells (FMC) are used to process a variety of products in the system and provide higher productivity. The components of the system such as robots and machines are more likely to fail when compared with the traditional manufacturing system due to their higher operating rate. Literature studied reveals that the failures of the machines have a high impact on the production rate of the system. In this work, two types of failures are considered i.e. wear-out failure and random failure. Wear-out failure can be eliminated by applying some maintenance plans but random failures are difficult to eliminate. So simulation experiments along with maintenance plans are studied to eliminate such failures. We also discussed two types of failure rate distributions i.e. exponential, and Weibull distribution and their effect on the throughput of the FMC. In this analysis, ARENA simulation model is made and simulation experiments were performed to analyze the throughput of FMC that consists of 2 machines in parallel and a robot for material handling. We assumed that failure is occurring in machines only and the robot is reliable throughout the simulation.

Keywords Flexible manufacturing cells · Reliability · Maintenance · Simulation · Production rate

20.1 Introduction

The requirement of the production systems that are flexible is created by the increasing demand for low cost, low-to-medium volume production of the modular goods with many different variations [1, 2]. Now a days the product demand and specification changes so rapidly. Due to which the manufacturing systems face so

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many challenges in the market due to fluctuations in the product demand. So the manufacturing systems need to accomplish these fluctuations as soon as possible so as to be a successful competitor in the market. So to obtain the desired products, Flexible Manufacturing Systems (FMSs) come into picture to get high productivity and higher flexibility. FMS is a production system composed of workstations having some Computer Numerical Control (CNC) machine and/or Numerical Control (NC) machines connected by a material handling system which is able to produce a batch of products having some set of variations and is controlled by an automated computer-controlled system. It includes material handling system also. The parts and products made by this flexibility fall under mid-volume- mid production range, in which the production volume varies from 5000 to 75,000 parts per year. If the annual production falls below this range, an FMS likely becomes an expensive alternative for the conventional manufacturing system. And if the volume of the production reaches above this range, then more sophisticated production system like transfer lines should also be taken into consideration. Groover [1] presents a list of various benefits that can be taken out of an FMS installation includes increment in machine utilization, fewer machine required, reduction in factory floor space required, greater responsive to change, reduced inventory requirements, lower manufacturing lead times, opportunities for unattended operations, reduced direct labor requirements and higher labor productivity [1].

20.2 Related Work

Patil et al. [2] Reliability analysis of CNC turning center based on the assessment of trends in maintenance data. Ghavijorbozeh and Hamadani [3] discussed application of the mixed Weibull distribution in machine reliability analysis for a cell formation problem. Vineyard et al. [4] discussed failure rate distributions for flexible manufacturing systems. Lin et al. [5] have considered imperfect PM models sequence that consists of improvement factors of the effective age and hazard rate. Savasar [6] has developed the mathematical models to compare and study the operation of the unreliable and fully reliable flexible manufacturing cell (FMC). Dessouky and Bayer [7] considered the model of maintenance process that provides the systematic approach to study the maintenance process of buildings that are fully occupied with the help of mechanical, plumbing and electrical system. Rupe and Kuo [8] presented an assessment framework for optimal FMS Effectiveness. Gupta et al. [9] presented about the selection of maintenance strategy for aircraft systems using multi-criteria decision making methodologies. Moustafa et al. [10] developed optimal major and minimal maintenance policies for deteriorating systems. Rezg et al. [11] developed the simulation model to study the optimal inventory control and the preventive maintenance strategy for a failing production system randomly that supplies the operation of assembly line on the basis of just in time configuration. Kuo and Chang [12] developed an integrated production scheduling and preventive maintenance planning for a single machine under a cumulative damage failure process. Savsar and

Aldaihani [13] studied and demonstrated the performance of the FMS considering preventive, corrective and opportunity-triggered maintenance policies. Maheshwari and Sharma [14] investigated unreliable flexible manufacturing cell with common cause failure. Tuysuz and Kahraman [15] presented modeling of a flexible manufacturing cell using stochastic Petri nets with fuzzy parameters. Sharma and Sharma [16] developed a complex system of mechatronic, i.e. modular automated production system that consists of electronic, mechanical and software subsystems to analyze the reliability aspect of the mechatronic systems. For this, they used the fault tree analysis to study the reliability of the system. Gaula and Sharma [17] developed the hybrid framework by incorporating the quantitative and qualitative techniques to analyze and model the failure aspects of FMC. Philip and Sharma [18] developed a stochastic reward net approach for reliability analysis of a flexible manufacturing module. For other studies undertaken by researchers in the area readers can refer to references [19–22].

20.3 Maintenance Strategies Applied in FMC

To find the optimum balance between the costs and benefits, researchers have concentrated their studies on preventive maintenance strategies. Age and block-based models are the two well known maintenance policies [1, 3]. In both models, equipment is carried out by scheduling preventive maintenance. In this paper, four maintenance policies have been implemented and evaluated on an FMC [6, 13].

1. **Corrective maintenance only policy (CM):** When any equipment fails, corrective maintenance policy is applied. A certain distribution is applied to assume time between failures. In this paper, we applied the exponential distribution because it facilitates the analysis to eliminate wear-out failures.
2. **Block-based PM with CM policy (BB):** In this case, Preventive maintenance is applied at the equipment at the end of each shift to remove the wear-out failures during the shifts. As compared to CM operations, PM operations are scheduled at the end of the shifts without affecting the production schedule. Evaluation of this policy has been studied under different mean time between failures and repair cases. This policy is shown by Fig. 20.1.
3. **Age-based PM with CM policy (AB):** In this policy, the preventive maintenance changes when a corrective maintenance is applied. Suppose T hours is fixed as time between PM operations. If after applying the PM operations and the equipment get failed and CM operations are applied before the next PM, the next

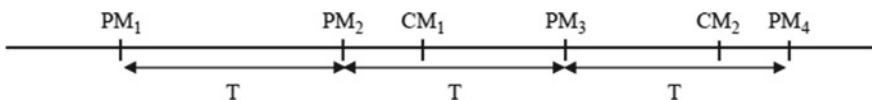


Fig. 20.1 Block-based PM policy

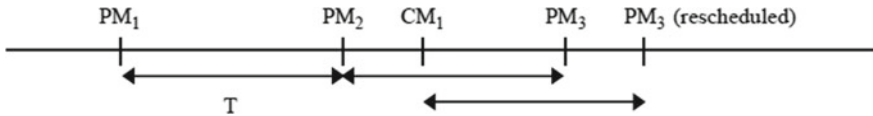


Fig. 20.2 PM operations under age-based policy

PM is scheduled T hours after the CM operation time. In simple words, we can say that PM operations are rescheduled when the CM operations are applied. This process is shown in Fig. 20.2.

4. **Opportunity-triggered PM with CM policy (OT):** In this policy, PM operations are applied when the failure mechanism occurs. In other words, we can say that if system fails, it requires both operations PM operation as well as CM operation. This is known as triggered preventive maintenance. As both operations are applied together, some parts are maintained by CM operations; hence PM time is expected to reduce. Certain percentage of reduction is assigned in the PM operations. In our case, we have taken 50% reduction in the PM time. These maintenance policies are applied under similar operating condition by using the simulation model. The FMC throughput is measured for each maintenance policy.

20.4 Objectives and Solution Methodology

The major objectives of the work are summarized as follows:

- To compute the parametric values for failure rate distributions.
- To develop the model using Arena Simulation Software (Student version [23]).
- To simulate the model for different maintenance policies.
- To study the different cases under maintenance policies.

Solution methodology consists of

- Failure data gathering and obtaining the parametric values for failure rate distribution
- Designing the system for the obtained parametric values
- Analyzing the production rate for different maintenance policies.

In this study, we examined the failure and repair time data of CNC turning center as well as robot. We have considered only failure and repair data of machine to obtain parametric values of failure rate distributions. Data for failure and repair time of machine is given in Table 20.1.

Table 20.1 Failure data of CNC machining center [2]

Failure time of machine tool (h)	Repair time of machine tool (h)	Failure time of robot (h)	Repair time of robot (h)
1276	25.1	110	9
720	26.2	115	8
1135	24	114	7
1854	22	120	11
1687	22.3	130	15
2570	21.2	132	14
2440	23.6	134	12
2547	27.9	109	11.5
1100	26.7	107	12.4
2117	28	129	8.8
1876	24.2	136	10.4
1633	25.9	117	16.8
2646	26.8	131	17.9
1556	28.2	140	16
2470	29.9	135	13
1250	23.2		
1895	23		
2607	24.8		
896	29.8		
401	30		

20.5 Simulation Modeling of FMC Maintenance Policies

To analyze the performance measures of FMC, simulation model of fully reliable and unreliable along with maintenance policies is developed. Simulation models are developed by using ARENA simulation software. We selected ARENA simulation because it is based on SIMAN language and it provides high flexibility and facilitates modeling of manufacturing system with various manufacturing-related programming blocks.

In our study, FMC consists of two machines and a robot (reliable) as shown in Fig. 20.3. Machines are having same failure rate arranged parallel to each other. Apart from this, it consists of two stations. One is input station, and another is output station.

For the given data in Table 20.1, we obtained the parametric values for different failure rate distributions and as shown in Tables 20.2 and 20.3.

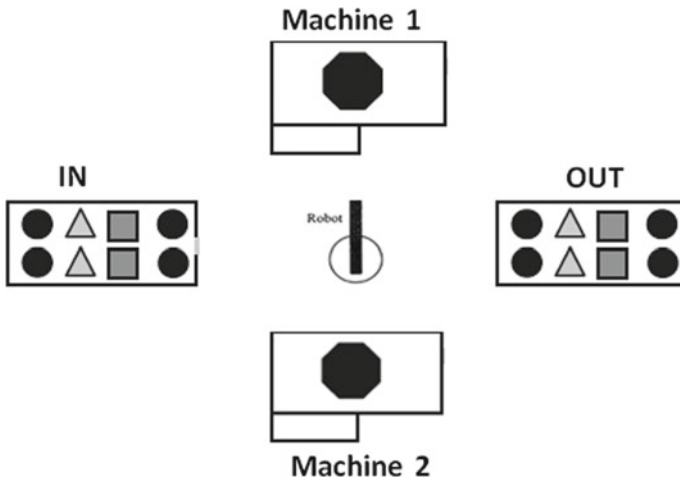


Fig. 20.3 A flexible manufacturing cell with 2 machines and 1 robot

Table 20.2 Time to failure of machine

Distributions	Parameters
Exponential	$\lambda = 1733.8$
Lognormal	$\mu = 7.35946$ $\sigma = 0.497851$
Weibull	$\alpha = 1946.48$ $\beta = 2.8937$

Table 20.3 Time to repair of machine

Distributions	Parameters
Exponential	$\lambda = 25.64$
Lognormal	$\mu = 3.23877$ $\sigma = 0.10649$
Weibull	$\alpha = 25.64$ $\beta = 10.5777$

λ = Mean for exponential distribution, μ = Log location parameter, σ = Log scale parameter
 α = Scale parameter for Weibull, β = Shape parameter for Weibull

20.5.1 Conceptual Design

The conceptual design for the simulation model that determines the maintenance strategy is presented. There are three distinct phases (as shown in Fig. 20.4) while designing the model: experimental setup, process simulation, and maintenance strategies.

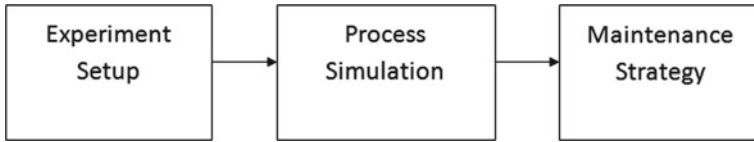


Fig. 20.4 Conceptual design

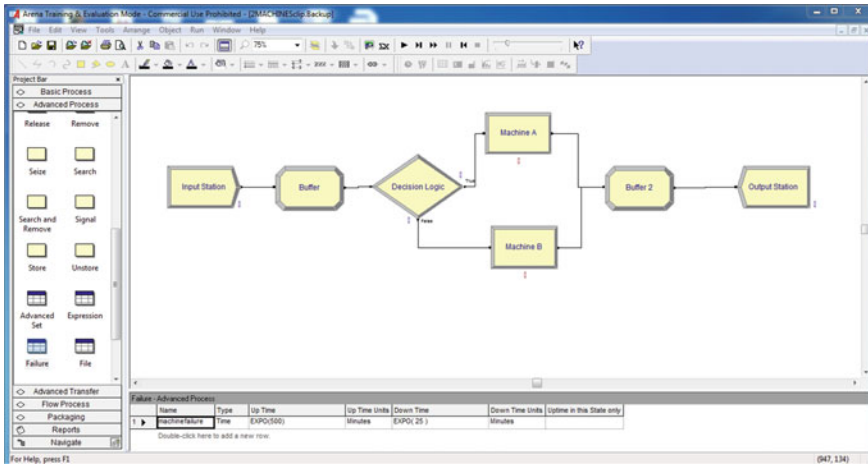


Fig. 20.5 Model in ARENA simulation software

Figure 20.5 shows the manufacturing model consisting of two machines with same failure rate. This model was developed using ARENA simulation software.

20.5.2 Simulation Experiments

A number of simulation experiments are carried out to learn the performance of FMC operations under different maintenance policies. The performance measure measured was the production output rate during the simulation period. With the aim to compare different maintenance policies and to conclude their effects on FMC performance, the case of fully reliable cell is also incorporated in our study. A simulation model was also developed for the fully reliable cell as well as five simulation models developed for unreliable cells with five maintenance policies. Thus, a simulation model was developed for each of the cases as: (a) a FRC; (b) a cell with CM; (c) a cell with BB; (d) a cell with AB; (e) a cell with OT. All simulation experiments were carried out for the function of the production cell over a period of 1 month (20 working days and 8 h per day or a period of 9600 min). In the case of PM, it was assumed that PM time of 30 min (or 15 min when combined with CM) is added to 480 min at the end

Table 20.4 Production rate of FMC with time between failures for unreliable and full reliable cell

S. No.	Time between failures (TBF)	Production rate (Unreliable)	Production rate (Reliable)
1	500	370	610
2	1000	375	610
3	1500	379	610
4	2000	385	610
5	2500	390	610
6	3000	450	610
7	3500	500	610
8	4000	505	610

of each shift. Ten simulation replications are made, and the performance measure, the average production output during the month, was obtained for each case. Other simulation associated parameters are given for each experiment.

20.5.2.1 FMC Case 1

This case shows the comparison between production rate for full reliable FMC and FMC with failure, i.e., unreliable. In this case, we took the time between failure exponentially distributed varying from 500 to 4000 min. In this case, we did not implement any maintenance policy. Comparison between production rate of reliable and unreliable cell is shown in Table 20.4. In Table 20.4, we can see that with increasing time between failures, production rate of full reliable remains constant but production rate of unreliable gets increased with time between failures.

Figure 20.6 depicts the production rate for different time between failures. From Fig. 20.6, we can conclude that there is steep increase in the production rate from 390 to 500 at 2500 min to 3500 min MTBF, respectively.

20.5.2.2 FMC Case 2

In this experiment, times between failures are taken exponentially distributed from 0 to T for the two machines taken in our proposed FMC (2 machines and 1 robot). In the unavailability of the preventive maintenance, the failure of the machine can take place anytime between 0 to T . But, when the PM (preventive maintenance) is implemented, failures due to wear-out are eradicated; only the random failures of chance causes stay that has constant failure rate and hence follow the exponential distribution that has mean time between failures of T . In this case, we took the value of T between 500 and 4000 min, in the increment of 500 min. Repair time is also taken exponentially distributed with mean 25 min for each machine. If we apply PM (preventive maintenance) on machine, it is supposed that the PM is completed in

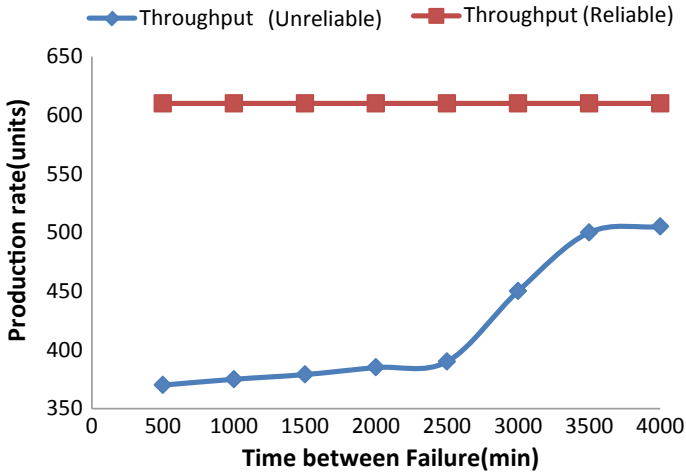


Fig. 20.6 Comparison of reliable and unreliable cell

the end of each shift and the machine takes 30 min for the preventive maintenance. If the CM (corrective maintenance) triggers PM and both are applied at the same instant, then there is a decrement of 50% in the PM time and the PM time comes down to 15 min, since CM tasks is also applied with it. Production output rate for each of the maintenance policies has been shown in Table 20.5. Production output rate obtained as the mean of ten simulation run and is considered as the mean of sum of the products manufactured during that month.

The fully reliable cell tells us the maximum possible production output (P_i) and is taken as a base to compare other maintenance policies. As it is seen from Fig. 20.7, implementing only CM without any PM is the worst policy of all. On the other hand, the best policy appears to be the opportunity-triggered maintenance policy (OT), ignoring negligible random fluctuations.

Table 20.5 Production rate of FMC under different maintenance policies for exponential MTBF

S. No.	MTBF (min)	Production rate (units)				
		CM	BB	AB	OT	FRC
1	500	370	483	485	490	610
2	1000	375	490	495	496	610
3	1500	379	510	520	524	610
4	2000	385	520	522	538	610
5	2500	390	525	528	550	610
6	3000	450	529	530	555	610
7	3500	500	530	533	560	610
8	4000	505	545	547	565	610

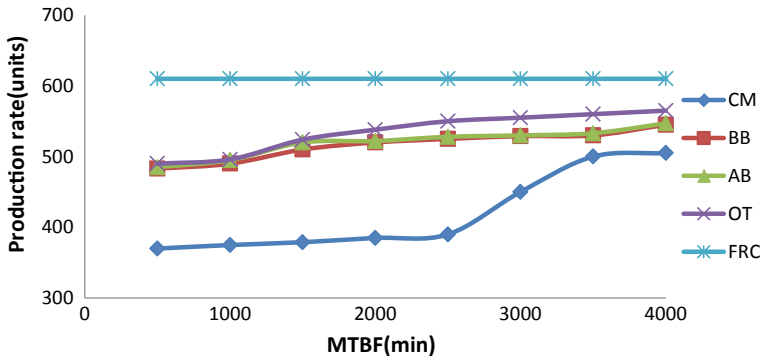


Fig. 20.7 Production rate for different maintenance policies for different TBFs

Between the age- and block-based policies, the age-based policy (AB) gives better results. Among all the policies with PM, block-based policy (BB) comes out to be the worst policy. As the mean time between failures (MTBF) increases, all of the policies reach a steady-state level relating to operational availability, but the gap between them is nearly the same at all levels of MTBF. In case of CM only policy, the production output rate sharply increases at the first increase of MTBF from 2500 to 3500 min.

20.5.2.3 FMC Case 3

In this case, we will follow the Weibull distribution and examine the throughput of cell for different maintenance policies discussed in Sect. 2. Firstly, we will determine the Weibull parameters for each time to failure.

For Weibull distribution that has $MTBF = \beta \Gamma(1/\alpha)/\alpha$, where these both parameters signifies α as shape parameter and β as scale parameter. These both parameters have to be calculated. For example, if $MTBF = 1500$ and $\alpha = 2$, then $\beta = 1692.2$. Similarly for $MTBF = 500$, $\alpha = 2$ and $\beta = 564.2$, for $MTBF = 2500$, $\alpha = 2$ and $\beta = 2820.95$ and for $MTBF = 4000$, $\alpha = 2$ and $\beta = 4513.5$ are used. Table 20.6 signifies the Weibull parameters for different times between failure that is calculated by using the Weibull formula. Table 20.7 shows the production rate for different maintenance policies under different mean time to failure that is Weibull distributed using the Weibull parameters.

Figure 20.8 depicts production rate under different maintenance policies for different MTBFs (Weibull distribution). Table 20.7 shows the values of production rate under different maintenance policies. This case shows the same trend as shown by the case 2 but production output rate under Weibull distribution is more than the exponential one that was discussed earlier. Here also the space between each maintenance policies is same, and they are increasing with the same rate. In this case, we find that even in the Weibull distribution, opportunity-triggered maintenance policy

Table 20.6 Parameters of Weibull distributions (α = shape parameter and β = scale parameter)

TBF	α	β
500	2	564.2
1000	2	1128.2
1500	2	1692.2
2000	2	2257.3
2500	2	2820.95
3000	2	3386
3500	2	3950.3
4000	2	4513.5

Table 20.7 Production rate for different maintenance policies for Weibull distribution

S. No.	MTBF (min) Weibull distributed	Production rate (units)				
		CM	BB	AB	OT	FRC
1	500	400	412	415	430	610
2	1000	452	475	481	495	610
3	1500	503	520	521	530	610
4	2000	511	525	529	538	610
5	2500	521	537	540	551	610
6	3000	530	540	545	559	610
7	3500	535	549	555	565	610
8	4000	545	561	565	571	610

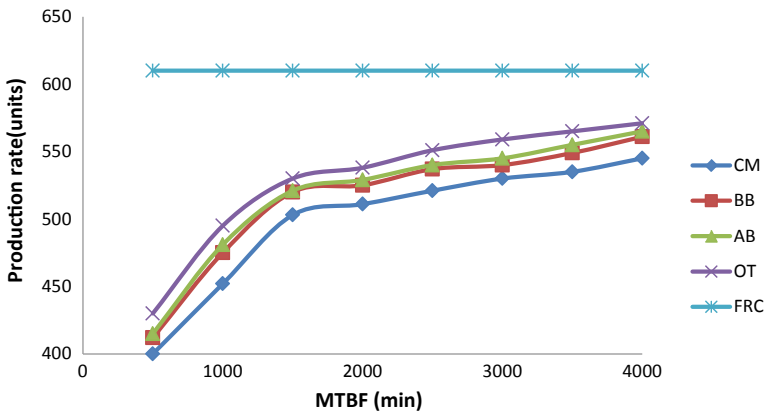


Fig. 20.8 Production rate under different maintenance policies for different MTBFs (Weibull)

is the best policy and the only corrective maintenance policy is worst among all maintenance policies as shown in Fig. 20.8.

20.6 Results and Conclusion

In this work, we analyzed the FMC using two failure rate distribution, i.e., exponential distribution and Weibull distribution, and along with it, we applied four different maintenance policies on the FMC. In this work, five cases have been discussed. The first case shows the comparison between reliable and unreliable cells. For reliable cell, production rate comes out to be 610. But for unreliable cell with the increase of mean time between failure, production rate increases. There has been a sharp increase in production rate from MTBF of 2500 to 3500 min. After that, it becomes constant. The second case shows the comparison of production rate under different maintenance strategies for different MTBFs that are exponentially distributed. The results of the second case show that CM policy is the worst among all other policies. But after MTBF of 3500 min, it reaches close to other maintenance policies. The third case represents the comparison of production rate under different maintenance policies for different MTBFs that follow Weibull distribution. The parametric values were calculated for Weibull distribution. The results of this case show that production rate of all maintenance policies increases with the same rate. The space between all maintenance policies is almost the same throughout the simulation. They increase sharply from MTBFs of 500 to 1500 min. After that, they increase at a slow rate. When we compared the production rate for two different failure distributions, we found that failure rate of Weibull distribution gives better result than the exponential distribution, but trend is same for different maintenance policies. It is because failure of the machine is not occurring at constant phase and failure data is most fitted to the Weibull distribution rather than the exponential one. Hence, we can say out of the two distributions, Weibull distribution comes out to be the best for maximum production rate. Also if we compare the maintenance policies implemented in failure time as well as repair time, CM only policy does not give the better result when it is compared with other maintenance policies. The maintenance policies that apply with PM are BB, AB, and OT. Out of these three policies, OT gives the best results, and between BB and AB policy, AB policy gives the better result. Hence, for the study of FMC, it was observed that we should consider the three things carefully. The first thing is the choice of simulation software. It should have high flexibility regarding the simulation and user. The second thing is the choice of failure and repair rate distribution that to which distribution our data is best suited or which distribution shape our data follows. The third thing is the choice of maintenance policies. It should be selected on the basis of production output rate.

20.7 Future Scope

Future studies can be done on analyzing the performance measures for three machines as well. The failure aspects of robots can also be included along with the machines during simulation. We analyzed the performance measures for exponential and Weibull distribution. Future studies can be done taking other failure rate distributions like lognormal distributions. Maintenance cost can also be investigated while performing the FMC under different maintenance policies.

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