Modelling and Simulation Studies on Effect of Maintenance Policies in FMS Environment

Dr. N. Selvaraj

***Abstract*— The aim of this work is to study various maintenance policies under Flexible Manufacturing System (FMS) environment using simulation approach by evaluating throughput and availability. Then it indentified the best maintenance policy. Mean Time Between Failure (MTBF) and Mean Time To Failure (MTTR) values are assumed to be Exponential distribution of 500minitues to 4000minitues in step of 500 and Normal distribution of mean 100minutes with std.dev10minutess respectively. In this work three existing maintenance polices namely Fully Reliable System (FRS), Corrective Maintenance Policy(CMP), Blocked based Preventive Maintenance (PM) with Corrective Maintenance (CM) policy(BBP) considered in addition to that the author has proposed new policy called HYBRID policy which are combination all three existing policies. Four simulation models have been developed using FLEXSIM simulation software and analysed with several experiments and shows that maintenance of any form has significant effect on performance measures of the FMS. However, the type of maintenance applied is important and should be carefully studied before implementation. The implication of this work is that any FMS system under consideration must be analyzed with respect to several maintenance policies and the best policy should be selected before blindly implementing a policy**

***Index Terms*— Availability, FMS, Maintenance, Simulation, Throughput**

I. INTRODUCTION

Flexible Manufacturing System (FMS) is typically to operate at 70–80% utilization, which is much higher than the utilization of traditional machines that can operate with as low as 20% utilization. A result is that, an FMS may incur four times more wear and tear than a traditional system. This requests the execution of effective maintenance plans on FMS. While maintenance actions can reduce the effects of breakdowns due to wear-outs, random failures are still unavoidable. It is important to understand the implications of a given maintenance plan on an FMS before its implementation. Kennedy (1987) argued several issues related to maintenance of FMSs.

However, no models are presented. Sun (1994) presented a simple simulation model of an FMS, which is operated under various maintenance policies. He tried to study the effects of maintenance policies by observing the time to failure, time to repair, and the maintenance times generated by simulation. Lin and Chien (1995) have discussed the maintenance system design problems in FMSs. Very little literature is found on maintenance-related issues of flexible manufacturing cells (FMC). Mehmet Savsar (2002) has discussed a procedure that combines simulation and analytical models to analyze the effects of corrective, preventive, and opportunistic maintenance policies on availability of a FMC. The effects of various maintenance policies on FMC production rate are simulated and the results are compared. A. Gharbia,J.P. Kenne(2005) have dealt with the production and preventive maintenance control problem for a multiple-machine manufacturing system to find the production and preventive maintenance rates for the machines so as to minimize the total cost of inventory/backlog, repair and preventive maintenance. Felix T.S. Chana,_, S.H. Chunga, L.Y. Chana, G. Finkeb, M.K. Tiwaric (2006) have used Genetic algorithm approach is to maximize the system efficiency by finding an optimal planning for a better collaboration among various processes. The optimization performance of the proposed GADG will be compared with other existing approaches, such as simple genetic algorithms to demonstrate its reliability. Mehmet Savsar(2006) have discussed a procedure that combines simulation and analytical models to analyze the effects of corrective, preventive, and opportunistic maintenance policies on productivity of a FMC. The production output rate of an FMC, which is a function of availability, is determined under different maintenance policies and mean time between failures. J.Ashayeri(2007 has developed new decision support tool embodies a set of structured heuristics methods for the coordination of tasks among maintenance crews which will help conduct different maintenance activities of manufacturing units in a more synchronized way leads to lower costs. Mehmet Savsar, Majid Aldaihani (2008) have developed a stochastic model to analyze performance measures of a FMC under different operational conditions, including machine failures and repairs. The model is based on Markov processes and determines closed-form solutions for the probabilities of system states that are used to calculate system performance measures, such as production output rate and utilizations of system components under different parametric conditions and equipment failures and repairs. J.P. Kenne, L.J. Nkeungoue (2008) have dealt with to minimize a discounted overall cost consisting of maintenance cost, inventory holding and backlog cost. The decision variables are the production, the machine preventive and repair rates which influence the inventory levels and the system capacity respectively. A computational algorithm, based on numerical methods, is used for solving the optimal control problem. Panagiotis H.Tsarouhas (2009) have described the classification methodology over a 2-year period of the primary failure modes in categories based on failure data of bread production line. He estimated the probabilities of these categories applying the chi-square goodness of fit test, and

Manuscript received july 04, 2016

Dr.N.selvaraj, Dept.Mechanical Engg, National Institute of Technology, Warangal, India

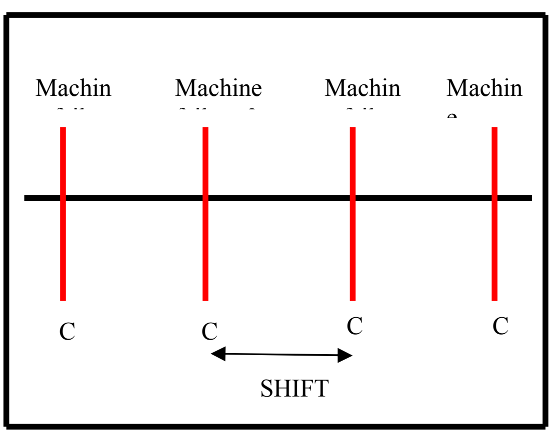
then calculated their joint probabilities of mass function at workstation and to improving the operation of the production lines. M. Celen, D. Djurdjanovic(2011) have devised an integrated decision-making policy optimizing a customizable objective function with respect to operation-dependent degradation models and production target. Optimization was achieved using a meta heuristic method based on the results of discrete-event simulations of a generic cluster tool. Merve Celen and Dragan Djurdjanovic **(2012)** they aimed to devise an integrated decision making policy for maintenance scheduling and production sequencing with the objective of maximizing an adaptive profit function, while taking into account operation-dependent degradation models and a production target. In order to obtain the optimal decision policy, a metaheuristic method based on the results of discrete-event simulations of the target manufacturing system is used. Mohd noor Akmal Khalid, Umi Kalsom Yusof and Ahamad Tajudin Khader(2013) FMS in a distributed factory environment to address the distributed production scheduling dilemma of FMS, where a significant part of the problem lies with preventive maintenance machine down-time. This paper introduced the Artificial Immune System (AIS) approach to tackle this underlying problem. The problem will be replicated and tested with several parameter tweaks to demonstrate its effectiveness in mitigating the issue. A.F.Kouedeu, J.P.Kenne, P.Dejax, V.Songmene and V.Polotski (2014), presented joint analysis of the optimal production and maintenance planning polices for a manufacturing system subject to random failures and repairs. Further to minimize a discounted overall cost consisting of PM and CM costs, inventory holding cost and blocking cost. They observed, failure rates is depends on the number of imperfect repairs, and as a result, the control polices of the considered planning problems therefore depend on the number of failures.

II. MAINTENANCE POLICIES [REF: 4, 7]

A. Fully Reliable system (FRS) or No maintenance policy:

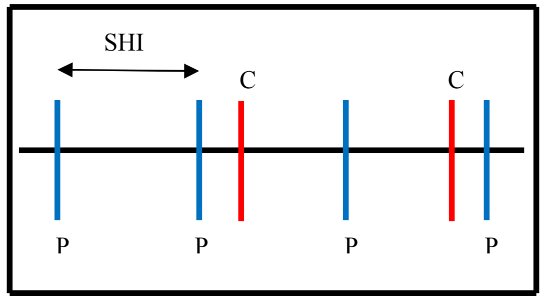
In this policy, the system is assumed to be fully reliable, no failure and no maintenance is performed.

B. Corrective maintenance only policy (CMP):



In this policy the FMS receives corrective maintenance only when any equipment fails. Time between equipment failures is assumed to follow a certain distribution, which was initially assumed to be uniform distribution. The idea behind using uniformly distributed time between failures is that the total failure rate can mathematically be separated into two components; namely, failures due to random chances and the failures due to wear-outs. This facilitates the analysis when preventive maintenance is introduced to eliminate wear-out failures as described in the next case.

C. Block-based PM with CM policy (BBP):



In this policy, the equipment is subjected to a preventive maintenance at the end of each shift to eliminate the wear-out failures during the shift. Regardless of any CM operations between the scheduled two PMs, the PM operations are always carried out as scheduled at the end of the shifts without affecting the production schedule. This policy is evaluated under different mean time between failure and repair. Each PM operation is carried out at the end of the shift as scheduled, without regard to the CM operations.

D. Hybrid policy:

An author has proposed new policy called Hybrid which is combination of CMP and BBP ie section 2.2 and 2.3. The maintenance policies described above are compared under similar operating conditions by using simulation models (16) with analytical formulas incorporated into the model. A general mathematical procedure has been used (4,7) to separate random failures from wear out failure. This separation is need in order to be able to see the effects of maintenance on the throughput and availability of the FMS when simulating the system

III. SIMULATION MODELING OF FMS MAINTENANCE POLICIES

Analyze the performance measures of FMS under different maintenance policies simulation models are developed for FRS, CMP, BBP and HYBRID using Flexsim simulation software.

A. Typical FMS Example

The mathematical model and the simulation models has been experimented with a typical FMS as illustrated in Figure 1 and corresponding Flexsim is shown in Figur.2. The performance measures have been considered as throughput and availability. The Automated Guided Vehicle (AGV) selects the parts and loads/unloads them to appropriate machines according to the processing requirements and the sequence programmed. Each part is operated on a different sequence of machines when the operations are completed; parts are placed on output pallet to be moved out of the machine. The speed of the AGV is set at 100 ft/min. Three types of parts enter the system. This combination was fixed in all cases of simulation to eliminate the effects of randomness in the arriving parts on the comparisons of different maintenance policies.

Table 1 shows processing time and operations sequence of parts which are in FMS.The simulation experiment has assumed to be 1 month (30 days and 8 h shift time). In case of PM introduction, it was assumed that PM time of 30 min (or 15 min when combined with CM) is added to the end of each shift. Other simulation related parameters are given for each experiment.

Table. 1 Processing time and operation sequence of parts

Part type and Operation of sequence	Lathe-L Milling – M in Minutes	Drilling-D Grinding – G in Minutes
Part 1 (L-M-G)	30	28
Part 2 (M-D-G)	28	26
Part 3 (L-D)	30	24

IV. SIMULATION RESULTS AND DISCUSSION

A. Experiment 1

In this experiment, MTBFs are assumed to be uniform distributed between 0 and T for all machines in the FMS. In the absence of any preventive maintenance (PM), a machine can fail anytime from 0 to T. However, when a PM is introduced, wear-out failures are eliminated; only the failures due to chance causes remain, which have constant hazard rate and thus follow exponential distribution with MTBFs equal to T. Here, the value of T is varied from 500 to 4000 min, in increments of 500 min. MTTR is assumed to be normal distribution with mean 100 and standard deviation of 10 min for all machines. If PM is introduced on a machine, it is assumed that the PM is done at the end of each shift and it takes 30 min for each machine.

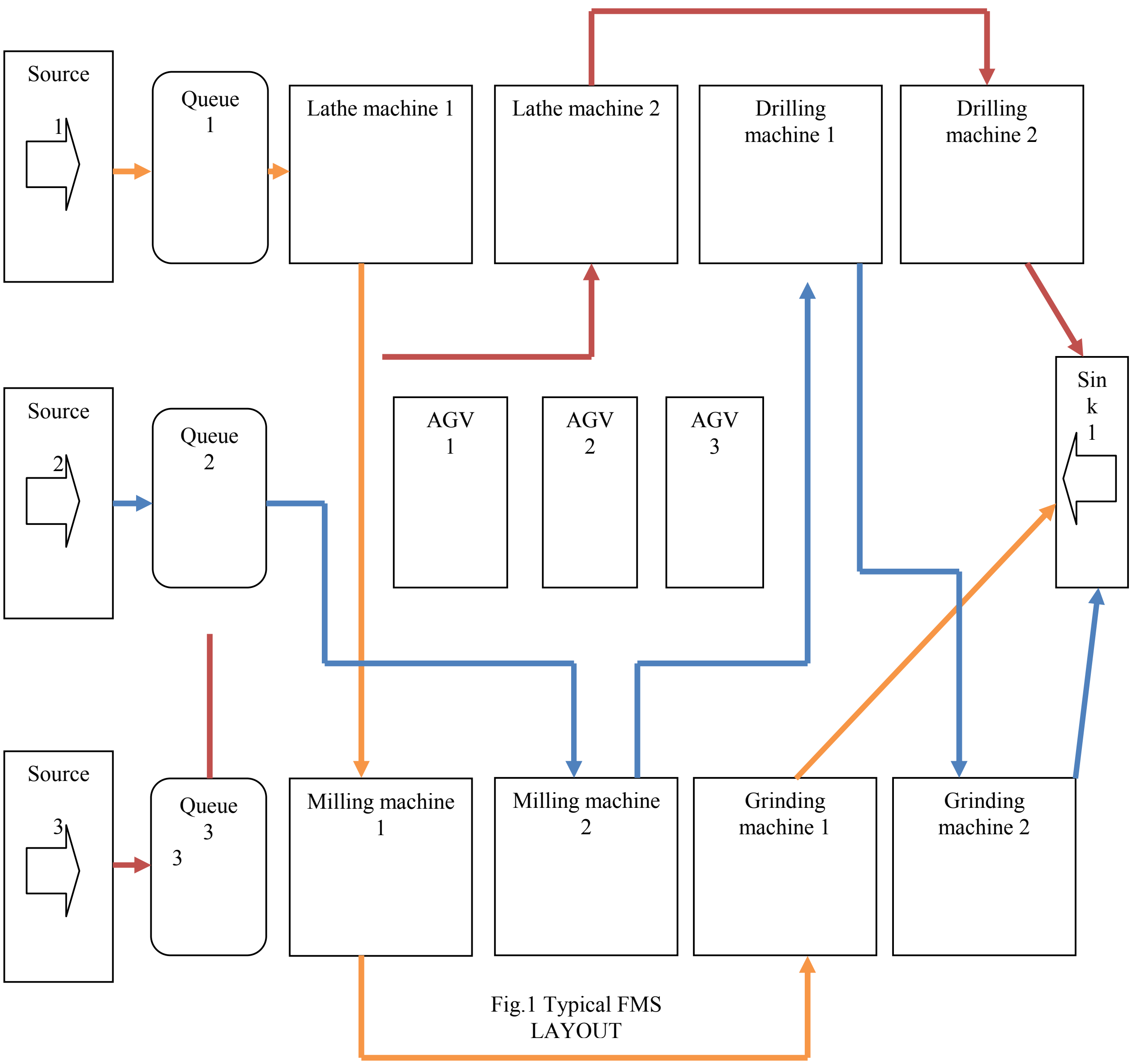


Fig.1 Typical FMS LAYOUT

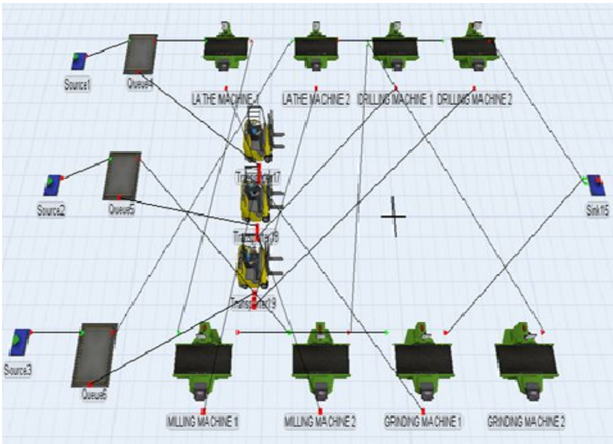


Fig. 2 Simulation model of typical FMS

If PM is triggered by the Corrective Maintenance (CM) and done at this opportunity, PM time reduces to half, i.e., 15 min, since it is combined with the CM tasks. The fully reliable system demonstrates maximum possible production output (*Pi*) and is used as a base to compare other maintenance policies. Throughput results for each one shown in table 2 and corresponding graphs have drawn in figure 3

Table. 2 Throughput under different maintenance polices with MTBF's

	Throughput			
MTBF in mints	CMP	BBP	HYBRID	FRS
500	2581	3239	3336	7800
1000	4250	4667	4823	7800
1500	5100	5432	5589	7800
2000	5520	5876	5884	7800
2500	5670	5998	5999	7800
3000	5780	6109	6117	7800
3500	5835	6211	6236	7800
4000	5998	6345	6368	7800

CM without any PM is the poor of all and the best policy appears to be the opportunity triggered maintenance policy, among all the policies with PM, block-based policy (policy 3 or BBP) appears to be the poor policy. As MTBF increases, all of the policies reach a steady level, but the gap between them is almost the same at all levels of MTBF.

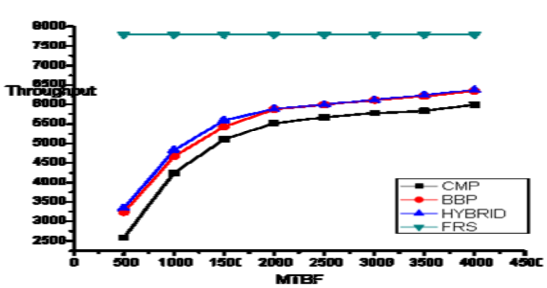


Fig. 3 Effect of Throughput under different policies

As the MTBF of the machines is less, they face more failures in less simulation time as a result productivity of the machines decreases and maintenance of the system increases. As a result throughput of the system decreased when there is less MTBF and conversely with more MTBF's. However Hybrid policy shows better than CMP and BBP.

B. Experiment 2

The effects of different PM times changing from 10 to 50 min at increments of 10 min on the FMS performance with various maintenance policies. Throughput results for each one shown in table 3 and corresponding graphs have drawn in figure 4

Table. 3 Throughput under different maintenance polices with PM's

	Throughput			
PM	CMP	BBP	HYBRID	FRS
10	5998	6345	6368	7800
15	5998	6345	6356	7800
20	5998	6345	6349	7800
25	5998	6345	6341	7800
30	5998	6345	6339	7800
35	5998	6345	6330	7800
40	5989	6334	6327	7800
45	5978	6328	6322	7800
50	5953	6314	6318	7800

An increasing PM time has no effect on fully reliable system and the system with CMP. BBP was not also affected, since the maintenance is carried out at the end of the shift when the equipment is not used for production. As the PM was increased, line productivity was naturally decreased in these cases but Hybrid policy shows better than CMP and BBP.

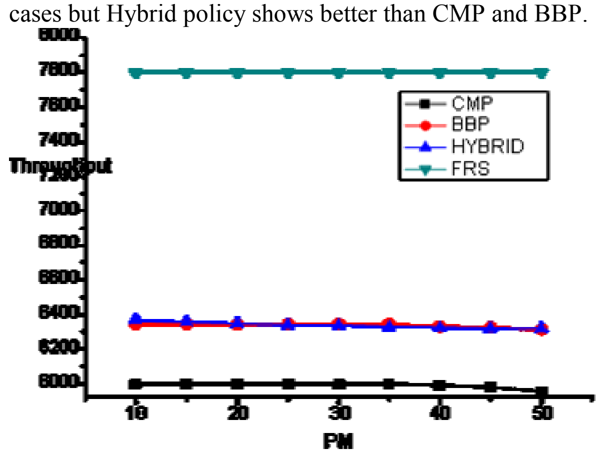


Fig. 4 Effects of variable PM time on FMS throughput

If PM is done in planned intervals, the life of the machines increases and it won't affects the productivity of the system. MP policy is without PM, so it is constant throughout the PM time interval. It has been observed that Hybrid policy shows better results

C. Experiment 3

The effects of maintenance policies on machines performance measures under different repair times, which were normally distributed with mean ranging from 40 to 120mints and standard deviation from 4 to 12mints. The remaining values are used same, as in the experiment 1. Throughput results for each one shown in table 4 and corresponding graphs have drawn in figure 5. It is observed that, the largest reduction in production rate was in Hybrid and smallest was in CMP.

Table. 4 Throughput under different maintenance polices and Repair Times

	Throughput			
RT	CMP	BBP	HYBRID	FRS
40	5998	6345	6368	7800
60	5835	6211	6236	7800
80	5780	6109	6117	7800
100	5670	5998	5999	7800
120	5520	5876	5884	7800

When the machine failures increase, the time to repair also increases and if repair time increases, the actual production time decreases and productivity of the system also decreases. This kind of approach is observed in this case. As the repair time increases the throughput of the system decreases with respect to policies.

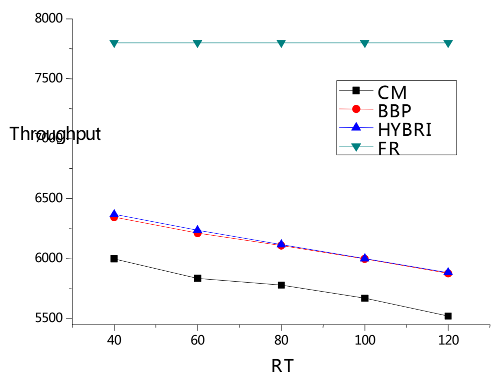


Fig. 5 Effects of repair time on FMS throughput.

D. Experiment 4

FMS equipments were assigned different MTBFs and the effects of maintenance policies were investigated under different equipment failure patterns. The time between failures was still assumed to be uniform, which reduces to exponential distribution when PM is introduced. While all the machine parameters were kept the same as in experiment 1.The MTTF values were assigned as Lathe 2500, Drilling 3000, Grinding 3500, and Milling 4000. Table 5 shows the results of throughput and the corresponding graphs shown in Figure6.

Table. 5 Throughput under Different and Equal MTBF

	Throughput	
Maintenance Polices	Different MTBF	Same MTBF
CMP	6577	6245
BBP	6345	6185
HYBRID	6348	6223
FRS	7800	7800

Mean repair time was kept as before at MTTR = Normal dist *(*100, 10) in all cases. PM time was set at 30 time units. The goal of this experiment was to compare the case when all equipment has similar failure patterns (MTTF = 2500 time units for all machines, as analyzed in experiment 1) to the case when equipment failure patterns are different and thus there is interaction between failure patterns of equipment (different MTBF for each machine as stated above for this experiment).

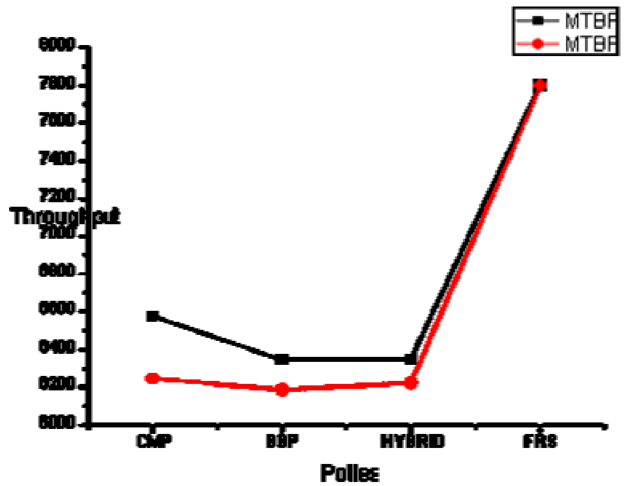


Fig. 6 Comparisons of maintenance policies under equal and different MTBF.

Under different maintenance policies for this experiment are compared to the results of experiment 1 and CMP policy was poor in both cases, i.e., the case when the MTBF are the same and the case when MTBF is different for all machines, and the CMP was the best among the maintenance policies. Fully reliable system was of course with the highest throughput as expected. The results show that there was no much significant difference between the case of similar failure pattern and different failure patterns of equipment in the case hybrid maintenance policy. Some variation was observed in other policies. However, the general trend is similar in both cases considered with somewhat more variation in the case of equal MTBF values.

E. Experiment 5

This experiment further investigates the effects of changing equipment failure patterns on machine performance with the four cases. The MTBFs was assumed to follow different range of patterns for each machine in the system. In particular, MTBF was changed from 500 to 4000 in Lathe, from 800 to 6400 in Milling, and from 700 to 5600 in grinding machine. All other machines parameters were set as in experiment 1. Table 6 shows the results of throughput and the corresponding graphs shown in Figure7. Further table 7 shows different equipment failure patterns for comparing maintenance policies when MTTR 100 minutes.

The difference between the maintenance policies was almost consistent for all cases. Hybrid was the best and CMP was the poor policy consistently. The difference between the CMP and the other maintenance policies significantly reduces as the time between failures increases.

Table. 6 FMS Throughput under Various MTBF

	Throughput			
Failure pattern	CMP	BBP	HYBRID	FRS
1	5912	6193	6293	7800
2	5856	6160	6289	7800
3	5689	5938	6212	7800
4	5489	5675	5839	7800
5	4993	5260	5482	7800
6	4521	4912	5159	7800
7	3742	4271	4472	7800
8	2581	2803	3031	7800

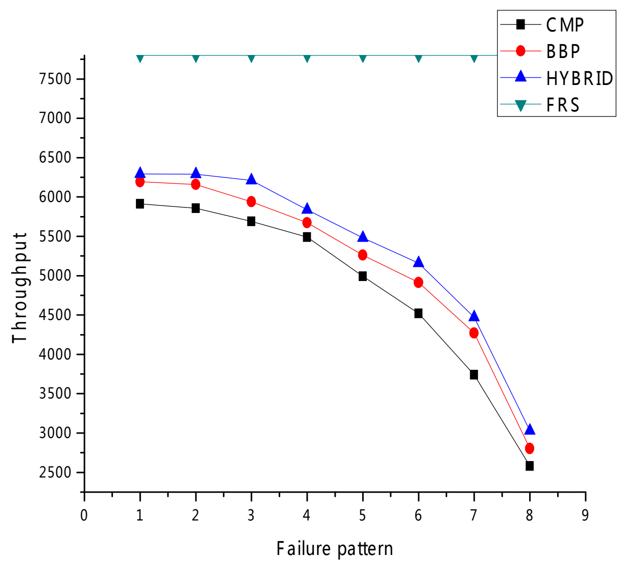


Fig. 7 Effects of maintenance policies under different MTBF.

Table. 7 Failure patterns for maintenance policies with MTTR 100 minutes

Availability

Table. 8 Effect of Availability on different machines

	Effect of availability on different machines			
Machine number	Lathe	Milling	Drilling	Grinding
1	0.8	0.875	0.833	0.857
2	0.9	0.937	0.916	0.928
3	0.95	0.969	0.958	0.964
4	0.96	0.979	0.972	0.976
5	0.975	0.984	0.979	0.982
6	0.98	0.987	0.983	0.985
7	0.983	0.989	0.986	0.988
8	0.985	0.991	0.988	0.989

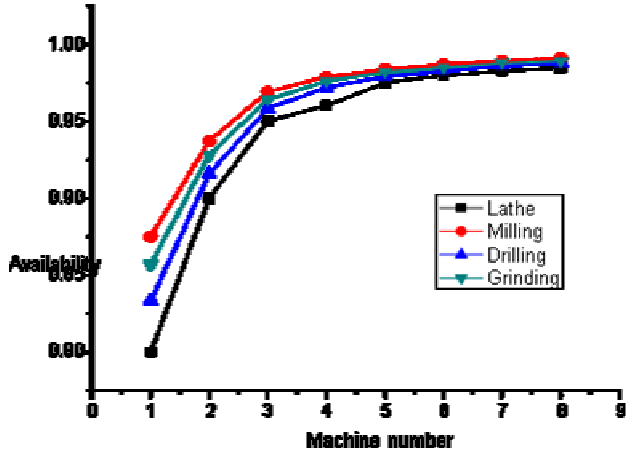


Fig. 8 Effect of availability on different machines.

Table 8 shows the effect of availability on different machines and corresponding graphs drawn in Figure8. It has been observed that availability of the machines reaches to a steady state level when there is increasing MTBFs. In the above experiment milling machine have high MTBFs compared to lathe machines. So milling machines shows the maximum availability compared to all other machines.

CONCLUSION

The objective of this work is to determine the effects of four maintenance policies on the performance measures of FMS by measuring Throughput and Availability. This model is analyzed by using mathematical formulation of failure rates and Flexsim simulation package. Four simulation models were developed namely FRS, CMP, BBP in addition to that the author has proposed new policy called Hybrid policy on the FMS. The results of the analysis of several experiments show that maintenance of any form has significant effect on performance measures of the FMS. However, the type of maintenance applied is important and should be carefully studied before implementation. The implication of this research is that any FMS system under consideration must be analyzed with respect to four maintenance policies and the best policy should be selected before blindly implementing a policy. Future studies can be carried out on the cost aspects of

Maintenance Policies	MTBF in minutes			
	Lathe	Drill	Grind	Mill
CMP	500	600	700	800
BBP	1000	1200	1400	1600
Hybrid	2000	2400	2800	3200
FRS	3000	3600	4200	4800

various policies if such data are available. The best cost saving policy can be determined depending on the specified parameters related to the repair costs and the preventive maintenance costs.

REFERENCES

[1] Kennedy.W.J, "Issues in the maintenance of flexible manufacturing systems." *Maintenance Management International* vol.7, 1987, pp 43–52.

[2] Sun.Y, "Simulation for maintenance of an FMS: An integrated system of maintenance and decision-making." *International Journal Advance Manufacturing Technology*, vol. 9, 1994, pp 35–39.

[3] Lin, Chinho, and Chien.T.W, "Maintenance system design problems for a flexible manufacturing system." *Computers and Industrial Engineering*, vol.28, no.1, 1995,pp 93–105.

[4] Mehmet Savsar, "Analysis of the Performance of A Manufacturing Cell Operating Under Different Failure Rates and Maintenance Policies" *The 6th Saudi Engineering Conference*, KFUPM, Dhahran, December, Vol. 4, 2002, pp 535-547.

[5] A. Gharbia, and J.P. Kenne, "Maintenance scheduling and production control of multiple-machine manufacturing systems", *Computers & Industrial Engineering , Science Direct- Elsevier*, vol, 48, 2005, pp 693–707.

[6] Felix.T.S, Chana, S.H.Chunga, L.Y.Chana, G.Finkeb,and M.K.Tiwari, "Solving distributed FMS scheduling problems subject to maintenance: Genetic algorithms approach" *Robotics and Computer-Integrated Manufacturing- Science Direct- Elsevier* Vol.22, 2006, pp 493–504.

[7] Mehmet Savsar, "Effects of maintenance policies on the productivity of flexible Manufacturing cells" *Omega- Science Direct- Elsevier*, vol,34, 2006,pp 274 – 282.

[8] J.Ashayeri, "Development of computer-aided maintenance resources planning (CAMRP): A case of multiple CNC machining centres" _ *Robotics and Computer-Integrated Manufacturing, Science Direct- Elsevier,* Vol.23, 2007,pp 614–623

[9] Mehmet Savsar, and Majid Aldaihani, "Modelling of machine failures in a flexible manufacturing cell with two machines served by a robot',*Reliability Engineering and System Safety - Science Direct – Elsevier*, vol.93, 2008, pp1551–1562

[10] .J.P. Kenne, and L.J. Nkeungoue "Simultaneous control of production, preventive and corrective maintenance rates of a failure-prone manufacturing system" *Applied Numerical Mathematics- Science Direct- Elsevier,* vol.58, 2008, pp 180–194

[11] Panagiotis and H.Tsarouhas,"Classification and calculation of primary failure modes in bread production line" *Reliability Engineering and System Safety - Science Direct Elsevier*, vol. 94, 2009, pp 551–557.

[12] M.Celen, and D.Djurdjanovic "Operation-Dependent Maintenance Scheduling in Flexible Manufacturing Systems" *Computers & Industrial Engineering, Science Direct- Elsevier,* Vol.17, 2011, pp 545-565

[13] Merve Celen and Dragan Djurdjanovic "Joint Maintenance and Production Operations Decision Making in Flexible Manufacturing Systems" *ASME 2012 International Manufacturing Science and Engineering Conference* Notre Dame, Indiana, USA, June 4–8, 2012, pp. 631-640

[14] Mohd Noor Akmal Khalid, Umi Kalsom Yusof and Ahamad Tajudin Khader. "Solving Flexible manufacturing system distributed scheduling problem subject to maintenance: Artificial immune system approach",*ICIC International* vol.7, number3(A) March,2013, pp 805-810

[15] A.F.Kouedeu, J.P.Kenne, P.Dejax, V.Songmene and V.Polotski "Production and maintenance planning for a failure prone deteriorating manufacturing system: A hierarchical control approach". *The International journal of Advanced Manufacturing Technology*, Sep 2014.

Flexsim User manual USA, 2007