3-Stage Maintenance Model for Flexible Manufacturing Systems

Gauraw A. Patil *

*Mechanical Engineering, Birla Institute of Technology and Science, Pilani

Abstract- Flexible manufacturing Systems (FMSs) typically operate at 70–80% machine utilization, which is much higher than the utilization of traditional machines that operate within range of 20% - 60% utilization commonly. (Savsar, 2005) A result is that an FMS may incur much more wear and tear than a traditional manufacturing system. This also means that failure of a machine attributes to much higher loss of production in FMS than in traditional manufacturing systems.

This suggests the execution of effective maintenance plans on FMSs. Maintenance actions can reduce the effects of breakdowns due to wear & tear, but random failures are still unavoidable. It is important to analyze the effects of a given maintenance policy on an FMS before its implementation. It is important to make sure if policy is minimizing the losses due to failure. This report discusses a procedure that combines simulation and routing flexibility to analyze the effects of various maintenance policies such as reactive, preventive or any other policies on the performance of an FMS. To achieve report accommodates the possibility that the best plan for maintenance may contain different policies for different machine types. It also makes sure that strength of FMS, routing flexibility is taken into the consideration. The effects of various maintenance policies on FMS performance are simulated and the results are achieved in monetary terms to be compared and determine the best maintenance plan for a given system.

Index Terms- Framework to choose Maintenance Policy, 3-Stage Maintenance Model, Flexible Manufacturing System.

1. INTRODUCTION

The objective of this paper is to devise a model for maintenance of Flexible Manufacturing Systems. First we take a look at the Flexible Manufacturing systems and get acquainted with them to know why, how and where the maintenance is required and what factors (such as high production rates, high machine costs, higher machine utilization and various other factors) need to be considered.

We move our discussion to the differences between Conventional Manufacturing System and Flexible Manufacturing System that need to be taken care of when designing the maintenance model for Flexible Manufacturing System.

While designing the model, the attempt is to make it as generalized as possible so that it can be applied to any Flexible Manufacturing System. We need to make sure that all the factors regarding maintenance activity are considered and all the advantages and disadvantages of a Flexible Manufacturing System are incorporated when designing a maintenance model.

Application of the maintenance model designed has to be kept as simple as possible so that it could be understood clearly and applied with ease.

2. COMPARISON OF FMS & CONVENTIONAL MS

To understand why we need to design a Maintenance Model for a FMS separately, first thing that we should know are the differences between Conventional MS & a FMS. Knowing these differences may let us know about the possible advantages of FMS as compared to the Conventional MS while designing the Maintenance Model. The step is also necessary to know the limitations of the FMS regarding application of different maintenance policies and disadvantages as compared to Conventional MS.

Few of the differences between the Conventional MS & FMS regarding maintenance modeling are –

2.1 Manually Controlled / Automated

Generally there is an operator present for every machine in a Conventional MS attending the machine. The operator keeps an eye on the performance of the machine & can keep a track of minor changes happening in its condition. The operator knows his machine well and with some experience and training he can understand and correct simple glitches in the machine. Also, from the conditions of machine such as vibrations, noise, speed, oil levels or accuracy, the operator can call in maintenance at the right times to avoid any discrepancy in production.

On the other hand, in a FMS, machines are automated and / or computer controlled. Operator or attendant is not present at all times to keep an eye. Also, the supervisor might not be well acquainted to the machine to recognize hidden failures or small failures. Hence, the possibility of a major failure becomes more probable, which can disrupt the production sequence.

Hence, it becomes important in a FMS to have a well scheduled, well established maintenance policy to avoid a major disruption in production.

2.2 Routing

This is the most important advantage that a FMS has against a Conventional MS regarding application of a maintenance policy. In a Conventional MS, generally, the job cannot be moved through different machines than the ones that they are assigned to. In a FMS, the routing flexibility allows us to route the job through different machines to achieve same sequence of operations. This is possible because the machines in a FMS are more flexible & general purpose. Hence, this flexibility needs to be taken into consideration when designing a maintenance policy for FMS.

2.3 MHS

As mentioned above, the routing flexibility is dependent on the machine flexibility of the system. Another factor that decides this flexibility is the Material Handling System used in the FMS. Hence, it is necessary to consider MHS while planning maintenance activity. For example, monorails, conveyors do not provide much of routing flexibility. But on the other hand, AGVs, RGVs, cranes can provide a much higher degree of routing flexibility.

Another factor regarding MHS that needs to be considered is that MHS also needs maintenance activity. Hence, this needs to be considered as a component in maintenance activity while planning maintenance. Many MSs use preventive maintenance for this component of the system.

2.4 Specialization of machines

In most of the Conventional MS, the machine flexibility is minimal. Once the final product is designed, the sequence of operations, machines required for that, layout and other things are decided. This leads to a dedicated MS with very low flexibility. In this type of MS, the machines are specialized for high production rates. Hence, having less flexibility.

In a FMS though, machines are general purpose machines. These machines are used to produce a wide variety of products or a product family instead of a single product or product part. Hence, a single machine could be a in the operation sequence of many products or product parts.

This tells us that shutting down a machine for maintenance may lead to disturbance in the sequence of a specific product in the conventional MS, but it could affect more products in a FMS.

2.5 Scheduling

As mentioned earlier, in a conventional MS, the machines are more specialized & routing flexibility is less. Hence, the scheduling of these machines is much simpler. They are assigned for specific operation in a specific sequence to manufacture a product or product part.

Whereas, the scheduling of general purpose machine in a FMS can be complicated as one machine can be used in production of different parts in a part family. Hence, whenever a machine is taken out for maintenance, to take advantage of routing flexibility the scheduling should be taken care of.

2.6 Volume

In conventional MSs the machine efficiencies are very low. In some Conventional MSs this rate could be as low as 20%, whereas, in a FMS, computerization and automation increases the machine efficiency considerably. It could be as high as 80% to 90%. The inference here is, even though Conventional MSs have specialized machines against general purpose machines in a FMS, rate of production in a FMS could be much higher than a Conventional MS.

Hence, very frequent, unnecessary maintenance activities could decrease rate of failure but, production loss in the maintenance downtime could outweigh the profits from decreasing failure rate.

2.7 Cost of Machines / Number of machines

During maintenance downtime of a machine, one can use excess production capacity to balance out any disturbance in production. This is the primary solution used by most of the Conventional MSs today.

In conventional MS, flexibility is less & hence machines are much more specialized (explained above). The cost of these machines is less as they are made for a specific job & hence not much complexity is required.

On the other hand, in a FMS, machines need a high degree of flexibility to provide FMS various kinds of flexibilities such as routing flexibility, mix flexibility, product flexibility, volume flexibility, etc. For this, the machines need to be general purpose which can perform many operations in any desired sequence. Machines such as CNC turning, VMC, UMC, etc. provide this machine flexibility. But to achieve this flexibility these machines need to be complex as there might be changes in sequence, processes, part designs, fixtures, dimensions & many other things. To accommodate these variables, the machines need to be very costly as compared to Manual Lathes, Milling machines, Drilling machines, etc. Also, for FMS, the MHS (Cranes, monorails, AGVs, RGVs, forklifts, etc.) can be a quite costly affair too.

Hence, keeping higher margins for production capacity is costlier in FMS than it is for conventional MS. Therefore, we should not miss the fact that though production capacity in FMS is very high, the excess capacity can be lesser due to higher machine utilization times & lesser idle machines (because of cost).

3. Maintenance Model

After knowing the characteristics of FMS and realizing the need of a separate Maintenance Model for FMS from Conventional MS, we move on to designing the Maintenance Model.

To simplify the problem and to concentrate on the maintenance model, we take some assumptions regarding the scope of the model.

3.1 Assumptions

I. Distribution of failure rates, mean & divergence for each machine is known before running model.

The rates could be manufacturer specified or found out by running reactive maintenance policy for a period of time to obtain data experimentally.

II. Distribution of repair time, mean & divergence for each machine‟s failure event is known before running the model. The failure event fits best in Weibull distribution or lognormal distribution. (M.L.Vineyard & J.R.Meredith, 1992)

This data needs to be obtained by the facility itself. The facility need to update database of repair events regularly to see any changes. These changes in distributions could lead changes in the optimum maintenance policy.

Detailed study regarding various failure rates has been done previously. (Vineyard, Amoako-Gyampah, & Meredith, 1999)

III. Considering the rarity of event, probability of two machines failing together is taken to be negligible and hence it is not considered in the model.

IV. Finding optimal routing patterns is out of the scope of this study. It can be done as a scheduling problem.

3.2 Objectives

To design a maintenance model, we need to define objectives of the maintenance model, so that we take all the factors that we studied above into consideration and extract maximum gains from every possible advantage to our use.

I. To obtain a maintenance policy that minimizes losses of a FMS due to maintenance activities.

II. To obtain a model that minimizes excess capacity of a FMS so that the facility could save capital investment in machinery.

III. To make use of the routing flexibility and machine flexibility. Hence minimize lost production due to maintenance activity.

IV. Rate of production in FMS is much higher, hence, longer maintenance activity stretches, higher is the production loss and hence higher is the monetary loss. Therefore, maintenance activity time should be taken into consideration.

V. To find a measure of performance for the different policies. A suitable parameter needs to be found out for the comparison.

VI. To find a technique that can be used to measure the performance.

VII. To find out best maintenance policy for every machine in the system.

3.3 Precautions

While concentrating on the objectives, we should take some precautions so as to achieve maximum gain out of the model.

The precautions applicable to the FMS facility in question need to be listed by the facility itself. Some of the precautions are listed down below –

I. Consider that machine utilization in FMS is very high.

II. Consider that Work-In-Progress (WIP) in FMS is kept very low to decrease lead time.

III. While considering routing flexibility changeover time losses should be considered as well.

IV. Factors for changeover time should be noted down cautiously. It is crucial in deciding whether changeover action should take place or not.

V. MHS should be taken as an active component of the FMS. Any part of MHS (E.g. AGV, RGV, crane, conveyer, transfer robot) should be considered as any other machine in FMS.

VI. Every component of the FMS that can affect the rate of production needs to be considered in the modelling.

VII. While calculating monetary loss due to a maintenance activity, the equation of loss should be formulated carefully.

VIII. Machines with similar distribution of failure events can be grouped together for analysis purpose. The grouping could be an important factor because it narrows down the procedure further.

IX. The distributions should be found out with highest possible precision and accuracy. Incorrect data regarding this may lead to false output.

X. It is possible that different maintenance policies are suitable for every machine in the facility. But before finalizing the maintenance strategy, the cost of application of these policies needs to be considered as well.

XI. The list of precautions should be created before applying the model to make sure that no important factors are left out.

4. 3-Stage Maintenance Model

Keeping the objectives and precautions in mind, we start modeling maintenance activity. To achieve all the objectives, we divide our model in three stages.
Stage-1: Routing
Stage-2: Obtaining Loss of Production Rate
Stage-3: Simulation

4.1 Routing

Why?

- *To achieve least 'loss of production' rate for machine failures*
- *To incorporate routing flexibility of FMS into the model*
- *Routing flexibility needs to be utilised because machine utilization in FMS is very high as compared to conventional MS*

- *It is also important because WIP in FMS is kept as low as possible, hence a long time for maintenance activity could lead to a large production loss*
- *Effect of every machine, every component that affects production rate of the system is found out and minimized*

Note

- *Obtaining output of this stage is out of the scope of this study as it is a problem of scheduling & resource planning.*
- *Separate algorithms are developed to obtain best routing pattern.*
- *While obtaining best / optimal routing pattern, do calculate the approximate changeover times and costs too.*
- *If changeover time is too large, obtain second best routing pattern option as well.*
- *The longer changeover time is, larger the changeover production loss will be, because the production will be stopped for changeovers.*

Procedure

- Gather information about processes & sequences of operations
- List the machines
- For each machine being out of the system, find routing pattern which compromises the least of required product mix

4.2 Obtaining Loss of Production Rate

In this stage we select a parameter to compare the performance of various policies. The best parameter to measure the performance of different policies is money. Lower the cost of running the maintenance policy after converting all the factors related to the maintenance policy, higher is its performance. Hence, we calculate and convert all the factors into monetary terms. This stage gives us the idea of how to convert various factors in monetary terms.

Why?

- *To compare the performance of various policies to be applied.*
- *To convert various losses, costs into a single parameter (here, monetary) to make comparison easier.*
- *To consider changeover losses, inspection time, production loss due to material shortage etc.*

Note

- *Small errors or failures need not be considered, as WIP buffer can work in the meantime*
- *Also the changeover times might be high and for small failures these might cost more*

Procedure

- Gather 'loss of production' rate for every machine failure from output of *Stage 1*
- It can be calculated for every machine as -
  [Minimum of (Maximum production rate that can be obtained, Maximum production rate that is required) from the FMS] – [Optimal production rate that is obtained without the machine in consideration]
- This rate is „N_i parts or products per unit time‟ in the loss of production term.
- Term P_i is the price of the product.
- Term „C‟ is a constant for every machine that includes losses due to changeover, observation time, miscellaneous factors etc.
- The term „C‟ could be taken as a constant because very small variances in the factors.
- If the variance for „C‟ is large, then its effect could be found out in simulation similar to the failure event or repair time or repair cost.
- The loss of production rate (R_L) can be measured in terms of $[(\sum N_i \; X \; P_i) \; X \; T + C]$ *where 'T' is downtime.*

As we have „loss of production‟ rate as well as costs regarding each of the product, we can convert time lost due to failure into monetary terms

4.3 Simulation

To measure the performance of every policy on every machine, we use the „Simulation Technique‟, in which we simulate a policy on a machine where we know the distribution of all the events. We can generate random numbers for given distribution, mean and variance, using various softwares. Many coding languages provide in built function for the same.

The simulation tables could be generated using Excel, MATLAB or codes can be written for simulation.

Why?

- *To simulate failures of every machine for each type of maintenance policy.*
- *To find out maintenance time & cost for every failure in a specified time period to obtain a real life condition.*
- *To obtain total time lost due to applying a specific maintenance policy for every machine in the specified time period.*
- *To calculate total monetary loss over a time of period from obtained data for every machine for various maintenance policies.*

Note

- *For Scheduled maintenance event, we consider that the maintenance time & cost will not vary much because every maintenance event is a regular exercise. Therefore, those factors can be taken to be constant.*

- *For Scheduled maintenance, time & cost can be expected to be lesser than Reactive maintenance as it is a routine whereas reactive maintenance is of unpredictable nature and it is for major failures.*

Procedure

Now we run a simulation for each machine with each maintenance policy that is going to be considered. There are various policies that can be applied. Procedure for some of these policies is given.

- In the Reactive Maintenance Policy, the maintenance activity is performed only when a failure is occurred. Simulation for ***Reactive Maintenance Policy*** can be done in following steps

a. Knowing the parameters & distribution of a machine‟s failure, failure event time can be predicted
b. At failure, repair time can be found out; knowing the distribution and it can be converted into monetary terms by using formula found out in *stage 2*.
c. Repair Cost distribution is known, hence repair cost can be predicted.
d. At the end of predetermined time period, total repair costs can be found out by summing up the repair costs for all the failure events.
e. Knowing the „loss of production‟ rate from *Stage 2* & total repair time from simulation, „lost production‟ costs can be calculated.

- In Preventive Scheduled Maintenance Policy, the inspection activity takes place at regular scheduled intervals. The best time interval for the inspection activity is the mean of failure event distribution as we know that mean of the distribution tells us the „expected value‟ of the overall distribution. Simulation for ***Preventive Scheduled Maintenance Policy*** can be done in following steps

a. For Preventive Scheduled Maintenance Policy, we select a regular time period at the end of which, a Scheduled Maintenance Activity will take place.
b. Now next step is similar to the Reactive Maintenance Policy simulation, predicting the time of failure event.
c. If Scheduled Maintenance / Inspection Activity appear before the failure event, the failure can be avoided by the inspection & failure event is predicted again from the time of Scheduled Preventive Maintenance occurred.
d. If failure event appears before Scheduled Maintenance, failure will take place & it needs to be resolved by Reactive Maintenance Policy mentioned above.
e. At the end of predetermined time period, total repair costs, lost production costs can be calculated as in the previous policy.

- Reactive Scheduled Maintenance Policy, as mentioned in the procedure, is a combination of Reactive Maintenance Policy and Preventive Scheduled Maintenance Policy. In this policy the Maintenance is scheduled after regular time intervals as in the Preventive Scheduled Maintenance Policy, but scheduling is reactive to the failure event. In this policy, the inspection activity is scheduled from the last failure event and not the last inspection event. Hence, it is a scheduled maintenance policy, but reactive to the failure event. Simulation for ***Reactive Scheduled Maintenance Policy*** can be done in following steps

a. This is a combination of Reactive Maintenance Policy and Scheduled Maintenance Policy.
b. The Scheduled Maintenance / Inspection activity takes place as in Scheduled Maintenance Policy and when a failure occurs, next Scheduled Maintenance is scheduled from the time of failure, whereas in the Scheduled Maintenance Policy it is irrespective of the failure event.
c. The procedure is similar to the Scheduled Maintenance policy.
d. If a Scheduled Maintenance activity is scheduled after every time period „T‟, then when a failure event takes place, the next Maintenance activity is scheduled at the (Time of failure + „T‟) instead of (Previous Scheduled maintenance activity + „T‟).
e. At the end of predefined time period all costs and losses are summed up for comparison with other policies.

- Similar simulations can be done for various policies & total costs for every maintenance policies can be compared.
- Policy with minimum total costs will be the most efficient one for that type of machine in the system

5. Conclusion

It has been well established that the role of maintenance is increasing every day in the automated manufacturing industries, with more and more complex systems being used. Another factor that makes it more important in FMS is that the utilization of the FMS is much higher than the conventional manufacturing systems.

Here, I have proposed a simple 3-Stage Maintenance Model, which is a simple procedure than can be applied to any FMS and maintenance policy can be deduced for the entire FMS.

As the name suggests, the methodology proposed has three stages. First stage involves in finding out the least possible losses due to downtime of machines. Second stage is used to convert the losses occurred in a maintenance activity, may it be time loss, monetary loss, into the monetary terms.

The third stage is the important stage which gives the maintenance policy to be applied. In this stage, we simulate various maintenance policies and then calculate the monetary loss occurred by application of each policy. The least cost policy is then applied to the machine in question. Simple software like

MATLAB, EXCEL can be used for the simulation stage. Also, specialized simple software can be produced for the same as the procedure is very straightforward and all the complexities have been taken care of.

Lastly, we should note the limitations of the model & hence modify it (especially stage 1) to avoid the limitations.

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AUTHORS

Gauraw A. Patil, B.E. (Hons) Mechanical Engineering,
M.Sc. (Hons) Economics),