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Effects of maintenance policies on the productivity of flexible manufacturing cells

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Abstract

Flexible manufacturing cells (FMCs) often operate with increasing failure rate due to extensive utilization and wear-outs of equipment. While maintenance plans can eliminate wear-out failures, random failures are still unavoidable. This paper discusses a procedure that combines simulation and analytical models to analyze the effects of corrective, preventive, and opportunistic maintenance policies on productivity of a flexible manufacturing cell. The production output rate of an FMC, which is a function of availability, is determined under different maintenance policies and mean time between failures.

Keywords: Maintenance; Reliability; FMC; Simulation

1. Introduction

Maintenance analysis is an important issue since the cost of maintenance in industrial facilities can go up to 15–40% of total production costs as reported by Sheu and Krajewski [1]. The trend toward increased automation has forced the managers to pay even more attention to maintain the complex equipment and to keep them in available state. While many maintenance related studies have been carried out on traditional automated systems, very few research can be found related to the effects of maintenance policies and failure rates on the operation of a flexible manufacturing system (FMS) and a flexible manufacturing cell (FMC) which is a subset or a smaller version of FMS. It is well known that during the extended useful life of an FMC, it will experience more wear and tear than a traditional machine operating over the same period of time. This is because, as indicated by Vineyard and Meredith [2], an FMC will typically operate at 70–80% utilization while a traditional machine may operate at as low as 20% utilization. The result is that an FMC may incur four times more wear and tear than a traditional machine. The effect of such an accelerated usage on system performance is not well known yet. However, it is fully realized that the accelerated usage of an FMC would result in higher failure rates, which in turn would necessitate and increase the importance of maintenance and maintenance related activities.

Traditionally it is known that the probability of failure would increase as a machine is aged, and that it would sharply decrease after a planned preventive maintenance is implemented. However, the amount of reduction in failure rate, due to the introduction of preventive maintenance (PM) has not been fully studied. In particular, it would be desirable to know the performance of a FMC before and after the introduction of a PM. It is also desired to know the type and the rate at which a preventive maintenance should be scheduled. In general there are two types of PM policies, namely, age-based and block-based preventive

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maintenance. The implementation of a PM could be at scheduled times (scheduled PM) or at other opportunities (opportunistic PM), which arise when the equipment is stopped due to other reasons. If the equipment is maintained only when it fails, it is called a corrective maintenance (CM) policy. Two other maintenance policies that could be seen in the literature are age and block replacement policies. In both cases, a PM is scheduled and carried out on the equipment. The difference is in the timing of the PMs. In the aged-based policy, if a failure occurs before the scheduled PM, the PM is rescheduled from the time the corrective maintenance is carried out on the equipment. In the block-based policy, on the other hand, the PM is always carried out at scheduled times regardless of the time equipment fails or the time a corrective maintenance is carried out. The best policy has to be selected for a given system with respect to its failure, repair, and maintenance characteristics. Depending on the availability of past data, costs should be taken into consideration in selecting the best policy.

The existing body of theory on system reliability and maintenance is scattered over a large number of scholarly journals belonging to a diverse variety of disciplines. In particular, mathematical sophistication of preventive maintenance models has increased in parallel to the growth in the complexity of modern manufacturing systems. Extensive research work has been published in the areas of maintenance modeling, optimization, and management. Dekker [3] presented an excellent review of maintenance optimization models. Cho and Parlar [4] presented surveys of maintenance models for multi-unit systems. Valdez-Florez and Feldman [5] also presented a survey of maintenance models for repair, replacement, and inspection of systems subject to stochastic deterioration. Vatn et al. [6] developed a generalized model based on influence diagrams for determination of an optimal maintenance schedule in a production system. Sheu and Krajewski [1] presented a decision model, based on simulation and economic analysis, for corrective maintenance policy evaluation. Almost all of the maintenance models try to find a balance between costs and benefits of maintenance for a machine.

Waeyenbergh et al. [7] and Waeyenbergh and Pintelon [8] have discussed detailed procedures, knowledge-based concepts, and frameworks in maintenance policy development and implementation in industry. Komonen [9] presented a cost model of industrial maintenance for profitability analysis. Lin and Chien [10] discuss the maintenance system design problems in flexible manufacturing systems. Very little literature is found on maintenance-related issues of flexible manufacturing cells. Gupta et al. [11] experimentally studied the interrelationship between downtimes and uptimes of CNC machines. They concluded that downtimes had dynamic influence on the uptimes of CNC machines with a delay effect. Kennedy [12] argues several issues related to maintenance of flexible manufacturing systems. However, no models are presented. Milne [13] presented a condition monitoring system to increase the availability of FMS and stand alone flexible machines. The system includes automatic data collection, statistical data analysis, advanced user interface, expert system, and maintenance planning. Lin et. al. [14] developed a closed queuing network model to optimize the number of standby units and the repair capacity for an FMS, which is referred to as maintenance float policy. Sun [15] 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. However, he did not incorporate into the simulation model the effects of preventive maintenance on machine failure times. Vineyard and Meredith [2] studied the effects of various maintenance policies on the failures of an FMS in actual operation. They have used the actual failure data and simulated the system under different maintenance policies without providing a mathematical relation between equipment failures and maintenance operations. They have set up a randomized block design and used multiple comparisons to determine the effects of different maintenance policies on different types of failures. Savsar [16,17] presented stochastic models for a FMC and obtained FMC availability assuming no preventive maintenance is performed. Further study is needed to evaluate the effects of preventive maintenance policies on FMC availability and to determine the amount of reduction in equipment failure frequency due to maintenance.

This paper presents analytical and simulation models to determine the performance of a flexible manufacturing cell operated under random failures and different maintenance policies. It is assumed that the FMC can be subjected to a purely corrective maintenance policy, a corrective maintenance combined with a preventive maintenance policy, or a preventive maintenance implemented at different opportunities. Since an FMC operates with an increasing failure probability due to wear-outs, its hazard rate is partitioned into a constant rate representing random failures and an increasing rate representing wear-out failures. In effect, the stream of mixed failures during the system operation cycle is separated into two types: (i) purely random failures due to chance causes; (ii) time-dependent failures due to equipment usage and wear-outs. The effects of preventive maintenance policies (scheduled and opportunistic), which are introduced to eliminate wear-out failures of a flexible manufacturing cell, are investigated by analytical and simulation models. This separation was possible by assuming uniform time between failures with hazard rate increasing by time. In particular, effects of various maintenance policies on system performance are investigated under different mean time between failures, as well as different maintenance and repair-related parameters.

2. Maintenance policies in FMC

Most of the previous studies, which deal with maintenance modeling and optimization, have concentrated on