Modeling of Maintenance Operations

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INTRODUCTION

Complex equipment and machinery systems used in the production of goods and delivery of services constitute the vast majority of capital invested in industry. These systems are subject to deterioration with usage and time. System deterioration is often reflected in higher production costs and lower product quality. To keep production costs down while maintaining good product quality, preventive maintenance is often performed on systems subject to deterioration. The cost of maintenance related activities in industrial facilities has been estimated by Mobley (1990) as 15-40% of total production costs and the trend toward increased automation has forced the managers to pay even more attention to maintain the complex equipment and keep them in available state. If the equipment is maintained only when it fails, it is called corrective maintenance (CM), while scheduled maintenance is called preventive maintenance (PM). It should be noted that preventive maintenance is different from pre-emptive maintenance. While pre-emptive maintenance plans are considered at the design stage to eliminate the maintenance requirement, preventive maintenance plans are applied during equipment operation in order to eliminate failures. In this chapter, we have considered preventive maintenance and related models to determine effective procedures and to minimize failures. 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 PM is implemented. However, the amount of reduction in failure rate, due to introduction of a PM has not been fully studied. In particular, it would be desirable to know performance of a system before and after the introduction of a PM with specific type and rate.

Extensive studies have been carried out in the areas of reliability and maintenance management. 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. Research work has been published in the areas of maintenance modeling, optimization, and management. Literature abounds with research papers in the areas of reliability and maintenance. While a survey of maintenance models for multi-unit systems has been presented by Cho and Parlar (1991), a review of maintenance optimization models is made by Dekker (1996). Sheu and Krajewski (1994) presented a decision model based on simulation and economic analysis for corrective maintenance policy evaluation. Some researchers, such as Waeyenbergh, et al. (2001), have discussed detailed procedures, knowledge based concepts, and frameworks in maintenance policy development and implementation in industry. Komonen (2002) presented a cost model of industrial maintenance for profitability analysis and maintenance models for production systems with intermediate buffers have been studied by Kyriakidis and Dimitrakos (2006). Leon Hijes and Cartagena (2006) presented a maintenance strategy based on equipment classification using a multi-criterion objective. Modeling of reliability and maintenance operations of flexible manufacturing systems (FMS) and flexible manufacturing cells (FMC) has been studied in detail by Savsar (2000, 2011a, 2012), Aldaihani and Savsar (2005,

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2008), and Savsar and Aldaihani (2008). Savsar (2005, 2006a) analyzed the effects of maintenance policies on FMC performance. Also, Savsar (2006b, 2008, and 2011b) developed discrete mathematical and simulation models to analyze preventive and corrective maintenance operations of serial production lines. Al-Salamah et al. (2010) discussed conflicting issues between operations and maintenance. Most of the models presented in the literature consider theoretical aspects of system reliability and optimum maintenance. In this chapter, we have considered analysis and models for equipment maintenance, which can be applied in practical situation. First, formulations and procedures are presented to determine various maintenance parameters based on data obtained from equipment operation. Then, several models and tools are presented for determination of best maintenance practice.

While most of the studies related to reliability and maintenance analysis are theoretical, limited numbers of practical applications are published in the literature. In this chapter, a detailed discussion of maintenance modeling and analysis is presented. In particular, basic formulations are constructed for estimation of various maintenance related parameters from available data; then, some models are extracted from the literature and incorporated into procedures for maintenance analysis. Estimated parameters are used in several formulations to determine the best maintenance policy for a given system. It is well known that equipment failures occur due to wear outs and random causes.

While random failures cannot be eliminated totally, wear out failures can be eliminated by PM operations and thus a reduction in CM can be achieved. The exact effects of PM operations in reducing CM frequency are modeled and illustrating examples are presented. Furthermore, formulation and models are presented for determination of optimum spare part order quantities for critical spares. Models for determining system down time and productivity before and after the introduction of PM are presented. Models and analysis developed and presented in this chapter could be useful for engineers and maintenance managers in practical applications.

FORMULATIONS OF MAINTENANCE OPERATIONS

One of the most important aspects of maintenance management is the utilization of data related to equipment failures and repairs. In particular, data related to corrective maintenance (CM) and preventive maintenance (PM) activities must be utilized effectively to obtain various maintenance related parameters. These parameters are then used to predict system performance measures under different operational conditions and to make operational decisions. . Equipment failures and repair operations are usually random events. It is not known in advance when equipment will fail and when a repair operation will be completed after it is started. Because of the random nature of these activities, it is necessary to calculate the estimated or expected values. In this section, estimation of different parameters from data and use of these parameters in calculating system performance measures are presented.

Component and Equipment Failure Rates

Mean Time Between Maintenance ($MTBM_{mt}$) and Average Active Maintenance Time (M_{mt}) are two important parameters to be determined for maintenance modeling and analysis.

Mean Time Between Failures of a component i ($MTBF_i$), is calculated as follows:

$$MTBF_i = \sum_{k=1}^{N_i} TBF_k \ / \ N_i \quad ; \text{i=1,....,C} \tag{1}$$

where N_i= sample size for failure type i;

C=Number of components or causes of failures for each equipment i.